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Handbook for the Extremely Low Frequency (ELF) Data Acquisition and Analysis System

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ABSTRACT

This handbook describes the digital data acquisition system built to record data in the 1 Hz to 600 Hz bandwidth from the portable underwater extremely low frequency (ELF) electromagnetic sensor unit. The sensors supported by the acquisition system are three-axis alternating magnetic field detection coils, three-axis alternating electric field sensors (electrodes) and three-axis seismic sensors; plus ancillary sensors such as pressure-depth, inclination and compass heading. The data acquisition system consists of the wet-end electronics package incorporating the controller board, 16 bit analogue to digital converter, low noise preamplifiers etc. and the dry-end electronics unit incorporating the power supply and computer. The data acquisition software for remote control of the total system and the analysis software which is linked to the data acquisition system is also presented. The analysis software which is purposely designed as an integral part of the acquisition system provides frequency domain spectral information (via the fast Fourier transform (FFT) algorithm) from the raw time series data and may be used both for quick look analysis during the data acquisition phase and for full analysis of data in slow time.

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1. ELECTRONIC AND ELECTRICAL HARDWARE

1.1 Introduction

The need to measure extremely low frequency (ELF) alternating magnetic (AM) fields in shallow seawater led to a prototype design which consisted of a single coil, laid flat on the seabed to detect the vertical component of the AM field in the 1 Hz to 1 kHz bandwidth [1]. The signal was amplified and cabled back to the recording platform in analogue form. The data was recorded on analogue tape in real time and analysed in slow time by either playing back into a spectrum analyser or by digitising and performing a fast Fourier transform with software [2].

Whilst successful, there were nevertheless several limitations, for example :

(a) only one component of the ELF-AM field was measured,
(b) undesirable dynamic range limitations were imposed by the tape recorder,
(c) the number of available conductors on the underwater cable precluded the use of other sensors,
(d) the use of a cable with a large number of shielded conductors to accommodate extra sensors soon becomes prohibitively expensive, and
(e) the only quick look analysis system was limited to the functions available on the spectrum analyser.

With the aim of overcoming the above restrictions, a complete underwater detection system was designed and built to measure ELF electric and magnetic fields from 1 Hz to 600 Hz and to provide frequency domain spectral information of recorded data both in pseudo real time and in slow time with more sophisticated software.

1.2 System Overview

The electronic/electrical hardware of the system consists of four main parts as shown in Figure 1. These are (i) influence sensors used for the measurement of three-axis electric, magnetic and seismic fields, together with ancillary sensors which determine the depth, heading and inclination of the underwater unit; (ii) an underwater electronics package (UWP); (iii) an underwater cable and (iv) a shore station. Part (i) is reported in a separate publication which is concerned chiefly with the design and calibration of magnetic induction coils as AM field sensors.

All the sensor signals except the compass output are amplified, filtered and then digitised with a 16-bit analogue to digital (A/D) converter in the UWP. The compass output is already in serial digital form. The A/D data are serialised and then transmitted to the shore station via the underwater cable. The received data at the shore station is de-serialised and then stored on a hard-disk. The data on the hard-disk may be transferred to a magnetic tape cartridge for permanent storage. The amplifier gain and switch settings in the UWP are selected by the operator at the shore station computer prior to a data collection run. These settings as well as START, STOP and other commands are transmitted to the UWP for execution.

The underwater cable consists of four small coaxial cables and two twisted-pairs. Two of the coaxial cables are used for the up-stream data and one twisted-pair is used for the down-stream power supply and command signals. The remaining conductors are reserved for other instrumentation.

1.3 Shore Station

The main components of the shore station are a computer with storage peripherals, a UART[1] board, a DC supply, an interface board and a cable breakout box. A discussion of the computer and storage peripherals and the UART board is given in Section 2. A schematic description is shown in Figure 2.

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[1]Universal Asynchronous Receiver/Transmitter

1.3.1 The DC Supply

The functions of the DC supply are to provide a power source for the UWP and to convey the command signals from the shore station to the UWP using only two conductors of the underwater cable. In this case a twisted-pair is used. The DC supply essentially consists of a custom designed isolated power supply and a commercial DC supply connected in series, forming a single floating current source. The commercial DC supply operates as a voltage booster and is required as a result of replacing the original choice of underwater cable with the current one which has much higher ohmic losses. The supply is configured as a floating 36 volt voltage source. A circuit diagram of the isolated power supply is given in Figures 3,4. It is essentially a constant current source with two preset current levels: 0.7 A and 0.8 A, which are switchable with a logic input. The serial command signals from the shore station computer are thus superimposed on the DC supply by driving this input.

Another logic input is provided to enable power on/off control by the computer. Two "window" detectors with LED indicators monitor the current and voltage levels respectively.

1.3.2 Interface Board

This board provides an interface between the UART board (located in the computer) and the two coaxial cables, and between the UART board and the DC supply. A circuit diagram of the interface board is given in Figure 5. Two high-sensitivity, high-speed opto-isolators operate as line receivers for the up-stream data. Although the coaxial cables have a characteristic impedance of 39 W, 50 W terminations are used to achieve a lower signal loss without increasing the wave-form distortion. Serial command signals from the computer are inverted and current-boosted to drive the DC supply's high/low current control. A modem control line "request to transmit" (RTS) is similarly buffered to drive the supply's on/off control.

1.3.3 Cable Breakout Box

The dry-end of the underwater cable branches out to individual conductor pairs which are then terminated with BNC and Cannon MS-series connectors at the cable breakout box. The pin connections are shown in Figure 6.

1.4 Underwater Cable

The underwater electromechanical cable is a 869 m long KLEIN Type 13300023 (side scan sonar) cable with a double sheath of galvanized steel armour and an overall outside diameter of 12.3 mm. The conductors include four small coaxial cables and two twisted-pairs. Measurements of the cable attenuation as a function of frequency for a twisted pair (red,#1/yellow,#9) and a coaxial line (black,#2,#3) are shown in Figures 7 and 8 respectively. These measurements are representative of all the twisted pairs and coaxial lines.

1.4.1 Cable Emulator

A cable emulator was designed for interfacing the UWP to the shore station electronics for laboratory testing and trials preparation. The emulator, see Figure 9, is very useful for such applications because the armoured cable weighs approximately one tonne and is not easily transported.

1.5 Underwater Electronics Package (UWP)

A block diagram of the UWP is given in Figure 10. Most of the electronics are mounted on single-height Eurocard size circuit boards. All the sensors except the AM sensors and the electronics are housed in the underwater casing which consists of a vertical polyethylene tube measuring approximately 0.2 m in diameter and 1.2 m in length. An underwater seal is provided by two 0 rings on each endcap, see Figure 11. The tube is flushed through with dry nitrogen prior to sealing. The depth sensor and three connectors for the AM input signals are mounted on the polyethylene bottom endcap of the tube. A connector for the main underwater cable and the DC supply are mounted on the aluminium top endcap which also acts as a heat- sink. The remaining electronics are physically located on twelve Eurocards (see Figure 12):

(a) three AM boards each containing an AM preamplifier, a signal selector, a post-amplifier, and an anti-aliasing filter,

(b) three AE (alternating electric field sensors) boards each containing a signal selector, a post-amplifier, and an anti-aliasing filter,

(c) an ancillary sensor interface board containing three geophone preamplifiers, an excitation voltage source, a depth sensor amplifier and interface circuitry for the inclinometer,

(d) an A/D converter carrier board,

(e) an A/D converter interface board,

(f) a CPU board containing a microcontroller, memory and leak-detector circuitry,

(g) a UART board containing two UARTs, two coaxial cable drivers and compass interface circuitry, and

(h) an I/O board containing output port latches and a calibration signal generator.

The interconnecting wiring diagrams for these boards are given in Figures 13, 14 and 15. The main functional building blocks are described below. A description of the control and data transmission electronics including the controller hardware, A/D converter interface, UARTS and I/O ports is given in Section 2.

1.6 AM Sensor Signal Conditioning

1.6.1 Preamplifiers

Each preamplifier consists of two low-noise opamps and a unity gain differential buffer, as shown in Figure 16. The overall gain is either 20 or 40 dB, being switchable with a bi-stable relay. The inputs to the preamplifier are low-pass

filtered to prevent any RF interference while the AM sensors are above water during tests. They are clamped to $\pm$ 0.65 volts for protection against transients. They may also be shorted by means of a relay to enable measurement of the system's self noise. The front-end opamps have a very low noise current, typically 0.5 fA Hz, which is essential for the highly inductive input sensors. The main contributor to the total output noise is the opamp's input noise voltage. The measured noise spectrum of the preamplifier is shown in Figure 17.

1.6.2 Post-amplifiers

The post-amplifier consists of an opamp connected in a non- inverting variable-feedback configuration as shown in Figure 18. Four gains 0, 10, 20 and 30 dB are selectable by varying the amount of feedback via a bank of CMOS analogue switches. One of three signals may be selected by a multiplexer (mux) as the input to the post-amp. These are :

(a) the output of an AM preamplifier,

(b) a calibration voltage, or

(c) a voltage V = 1000 x i_{cal} where i_{cal} is a calibration current driving the excitation coil of an AM sensor.

The selected signal is high-pass filtered with a single-pole 0.1 Hz filter to eliminate any DC offset.

1.6.3 Anti-aliasing Filters

The anti-aliasing filter is an eighth-order elliptic low-pass type with a corner frequency of 600 Hz. It is implemented with four stages of quad- opamp state-variable active filters as shown in Figure 19. The first three stages have unity DC gain. The final stage has a gain of 6 dB and its output is clamped to $\pm$ 11 volts. The measured pass-band and stop-band frequency responses of the filter are shown in Figures 20 and 21 respectively.

1.7 Geophone Signal Conditioning

1.7.1 Preamplifiers

The preamplifier is a simple single-ended opamp design with a fixed gain of 40 dB as shown in Figure 22. The input is clamped to $\pm$ 0.65 volts for protection against transients.

1.7.2 Post-amplifiers and Anti-aliasing Filters

The post-amplifier and anti-aliasing filter are similar to those for the AM sensors (see Section 1.6) except that the three selectable input signals to the post-amplifier are :

(a) the output of a geophone preamplifier,

(b) a calibration voltage, and

(c) the output of an electric field sensor preamplifier, as a provision for future expansion.

1.8 Ancillary Sensor Signal Conditioning

1.8.1 Pressure Depth Sensor

Three basic functions - transducer excitation, amplification and low- pass filtering are implemented with a hybrid module Analog Devices Model 2B31K as shown in Figure 23. The excitation voltage and the amplifier gain are set to 5 volts and 40 dB respectively. A power-down circuitry is added to enable the module to switch off while idling, thus reducing system power dissipation.

1.8.2 Inclinometer

The excitation voltage for the depth sensor (see Section 1.8.1) is also used for driving the inclinometer, as shown in Figure 23. The inclinometer outputs are low-pass filtered with two simple single-pole filters.

1.8.3 Leak Detector

The leak detector is a simple voltage comparator with a high input impedance, as shown in Figure 25. A leakage resistance of approximately 300 kW or less across the input terminals will cause the output to become active. The actual sensor consists of two concentric conducting rings mounted on the internal bottom polyethylene endcap. The rings were machined from double sided printed circuit board laminated with copper on each surface.

1.9 Analogue-to-Digital Subsystem

The A/D subsystem is a Data Translation Model DT5716A Data Acquisition Module mounted on an adapter board shown in Figure 24. It consists of a 16-channel single-ended input multiplexer, a sample-and-hold amplifier and a 16-bit A/D converter. The full scale input voltage is $\pm$ 10 volts. The output data are in two's complement format. The maximum throughput rate is 20 thousand samples per second.

1.10 Coaxial Cable Drivers

A dual CMOS driver integrated circuit ICL7667CPA is used for each cable driver as shown in Figure 25. Only half of each IC is used in order to keep the heat dissipation of the device below its specified limit.

1.11 Calibration Signal Generator

The pseudo random noise generator (PRN) is intended to provide a signal for a quick go/no-go test of the system rather than a precision calibration source. The basic signal is generated with a 31-bit shift-register with appropriate feed-back as shown in Figures 26 and 27 and closely approximates a white-noise signal from DC to 5 kHz. This signal is then gated and buffered to provide four individually selectable outputs, one voltage and three current sources. The current from each current source is fed through a 1000 Ω resistor such that the voltage drop across the resistor may be used to monitor the actual output current (see Figure 10).

1.12 DC Supply and Command Signal Separator

A circuit diagram of the DC supply and command signal separator is given in Figure 28. When the UWP is transmitting data upstream, the input power to the DC supply is a constant current of 0.7 A from the shore station. It is fed into a simple shunt voltage regulator where it is converted into $\pm$ 18 volts. This configuration minimises current fluctuations in the supply conductors in the underwater cable resulting in less AC magnetic emission. The shunt regulated voltages are then converted to + 5 volts with a DC/DC converter, and also regulated into two sets of bipolar supply rails: +/- 15 volts and +/- 13.6 volts. The +/- 13.6 volt rails have lower output noise and are used for supplying the AM preamplifiers. While the system is not collecting data, command signals from the shore station which modulate the DC supply current, are extracted with an opto-isolator operating as a current sensor (see also Section 1.3.1). Crow-bar circuits are incorporated to provide protection against over-voltage and thermal overload.

2. *UNDERWATER SYSTEM CONTROLLER*

2.1 Introduction

A basic design parameter is that the measurements of the influence fields have a 90 dB dynamic range and a bandwidth of 1 Hz to 600 Hz. To achieve this the system digitises the data via a 16-bit A/D converter operating at 1800 samples/second/sensor-axis prior to transmission to the surface. Up to six channels (consisting of any axis of any sensor type) of data may be transmitted to the surface via two coaxial lines, each of which carries 8 bits of the 16-bit data in an RS232 format.

At the surface, data are received into an IBM compatible desk top computer which also communicates with the UWP for command and control purposes. Data are stored on the hard disk of the computer for later retrieval and analysis.

The following is a description of the hardware and software forming the digital controller for the ELF instrumentation system. The circuitry is installed in the underwater housing in conjunction with the analogue acquisition systems and a 16-bit A/D Converter. Bi-directional communication with the surface is via a multi-core cable to a custom UART board installed in an IBM compatible PC. The primary purposes of the controller are :

(a) to accept acquisition parameters from the surface computer control unit,

(b) to interpret the parameters and programme the system,

(c) to control the operation of the A/D converter, and,

(d) to format and transmit acquired data to the surface.

The controller is a substantially CMOS logic system based on a Motorola CMOS microprocessor, MC146805E2, combined with general purpose Monitor software contained in a 27C16 EPROM. Operational software is downloaded from the surface into 4 k of RAM, its presence being detected by the Monitor software as an extension of the Monitor program. The controller is constructed on four 160 x 100 mm Eurocards with a common backplane. A header terminated flat cable connects to the ADC card and a second cable connects to the various control switches in the analogue section of the acquisition system.

2.2 Controller Hardware

2.2.1 Controller Card

This card, see Figure 29, contains the 6805 microprocessor /EPROM/RAM, address decoding, independent reset command detector and a leak detector circuit. The 6805 processor has an 8-bit data bus on to which are multiplexed the lower eight address lines. The latter are latched by the address strobe (AS) and, combined with the upper five address lines, form the address bus. Decoding provides selection lines for 0000-07FFh, 0800-0FFFh (RAM), 1000-17FFh (RAM) and 1800-

1FFFh (EPROM), 0000- 07FFh is further decoded to select 0080-008Fh, 90-9Fh, A0-AFh, B0-BFh which are available on the backplane as X80, X90, XA0 and XB0. XC0, XD0, XE0 and XF0 are also decoded but are not currently used.

The least significant latched address lines A0-A3 are available on the backplane. Using the X lines as block selectors this provides up to 64 individual I/O port addresses. Data I/O are controlled by the read (RD) and write (WT) lines which are derived from the microprocessor Read/Write (R/W) and data strobe (DS). All decoded address select lines are active low as are RD and WT. AS and DS are active high. The multiplex data and address bus is connected to the backplane as AD0-AD7.

Microprocessor reset is independent of and overrides all other functions. If the card input RESET lines goes low, a combined 12 kHz oscillator and divider (4060) is enabled. After approximately 10 msec, the 2^8 division output goes high and this, inverted, is applied to the 6805 RST pin. Thus reset will occur if the RESET line is held low for more than 10 msec. This line is connected to the serial communications line from the surface computer. Normal serial transmissions do not contain a low level longer than 2 msec (at 4800 baud); the reset command may be issued by transmitting a series of BREAK characters.

The 6805 provides two special memory mapped 8-bit ports (port A and Port B) in which the individual bits may be programmed for input or output and whose status may be individually sensed or set by a range of 6805 software opcodes. The 8 bits of port B (PB0-PB7) are connected to the backplane; they are used for sensing ADC and serial UART status lines (see later) and for simulating a water leak condition to test the leak alarm.

The leak detector transducer is a pair of contacts just within the O ring seal. They are connected to the controller card via the backplane. One contact connects to common, the other to one input of a Schmitt trigger and via 1 MW to Vdd. Should water ingress lower the impedance between the contacts the Schmitt trigger changes output state causing a low level interrupt signal at the IRQ pin of the 6805. Software may then cause an alarm to be given at the surface. The other input of the Schmitt trigger is connected to PB7 of port B. It is normally held high but when forced low under software control it simulates a leak.

2.2.2 UART Card

This card contains the circuits for serial I/O communications with the surface and also with the internal compass, see Figure 30. Two National NSC858 CMOS UARTS are used. These are referred to as the primary and the secondary UARTS. Transmissions from these to the surface are driven up separate coaxial lines within the main cable by ICL7667CPA line drivers.

The primary receiver receives transmissions from the surface multiplexed onto the power lines. The secondary receiver is connected to the output of the compass unit. A baud rate clock is supplied by a 2.4576 MHz crystal in conjunction with the internal oscillator circuit of the secondary UART; the oscillator output drives both UART baud clocks.

Operation of the UARTs is software controlled in one of three modes. For command and control communications with the surface, the primary UART only is used, configured for 4800 baud, 8-bits, no parity, 1 stop bit. To transfer data from the compass to the surface, the secondary UART is configured to receive with the same configuration; compass data are received by the secondary, processed by the controller and transmitted to the surface by the primary. For full ELF data transmission both UARTSs are configured to transmit (no receive function) at 153 600 baud, 8-bits, even parity, 1 stop bit.

The primary UART receiver input line is also connected via the backplane to the RESET detector on the controller card. A continuous BREAK (low level) on this line will cause a processor reset regardless of the UART configuration. Following a reset the processor reconfigures the UARTs to the command and control mode.

The UART interface with the 6805 is via the data bus and the backplane control lines from the controller card. Each UART has a chip select line, X80 for the primary and X90 for the secondary. Address lines A0-A3 are latched into the UART by AS from the multiplex data/address bus thereby selecting one of twelve internal registers. Data are written into the selected register if WT is active or read out if RD is active. One can refer to the NSC858 data sheet for specific information on the register functions.

The UARTs may be programmed to activate an interrupt request line if certain conditions pertain e.g. transmit buffer empty. The primary UART request line is connected to PB3 of the 6805 port B, the secondary UART to PB4 and the ANDed combination to PB0, all lines being active low.

A power supply switch (PSW1) for the compass is included on the UART card, providing 12.6 volts when switched on. The compass connects via a three pin Utilux plug/socket.

2.2.3 Analogue to Digital Converter Control Card

The function of the ADC control card, in combination with controller software, is to provide correct sequencing for multiplexer address selection and strobe and for ADC data bus access. A schematic diagram of the card is shown in Figure 31.

Digital input to the ADC consists of a four bit address for the analogue input multiplexer (AADR0-AADR3) and a convert initiate strobe (ASTB). On receipt of the strobe the multiplexer address is latched in and a 30 μs sampling period commences. Following this is a 20 μs conversion period. On completion of the conversion, the output data valid (AEOC end of convert) line goes high and remains high until the next conversion (not sampling) period commences. Whilst the data are valid they may be accessed onto the data bus (ADAT0-ADAT7) in two bytes by successively activating output enable lines (AENLO and AENHI); note that if AEOC is ignored invalid data may be accessed.

Functions within the ADC control card are accessed by the processor at addresses decoded from XA0 and A0-A2. Different functions are accessed depending whether the operation is a RD or a WT. Read functions are mapped at addresses 00A0 and 00A1 (ADC data bus access). Write functions are mapped at addresses 00A0-00A4; 00A5-00A7 are used off card.

The system operates in acquisition cycles or SETs at 1800 sets per second. Within each set up to eight analogue inputs may be sampled, converted and accessed; however UART serial data transmission rate restrictions limit the number to six channels per set if consecutive sets are desired.

The number of channels per set (SETLEN) is transferred from the processor into a latch at address 00A0(WT). The analogue input multiplexer address for each channel is stored in latches at addresses 00A1-00A4(WT). Eight bit latches are used, each containing two 4-bit addresses. For example, the least significant 4-bits at address 00A1 contain the multiplexer address for the 1st channel of the set and the most significant 4-bits the multiplexer address for the 5th channel. The latch outputs are multiplexed onto the 4-bit ADC address lines.

Timing for the ADC sequence is derived from a 1.8432 MHz crystal. The crystal drives a binary counter, three consecutive outputs of which define eight timing zones within each set. The slowest of the three outputs (Q10) runs at 1800 Hz thus defining the set repetition rate. Each timing zone is 69.5 μs and is allocated to one conversion of one analogue multiplexer input.

The three clock outputs are decoded to select the appropriate stored ADC multiplexer address which is enabled onto ADC lines AADR0-AADR3. This occurs at the start of each timing zone. 17 μs later, a 1 μs monostable is triggered to provide the convert initiate strobe (ASTB). The clock outputs are compared with the latched SETLEN and when the zone number exceeds SETLEN an End of Set (EOS) line goes low. This inhibits the strobe and is also connected to PB2 of the 6805 port B for detection by software.

The multiplexer address and strobe generation, once programmed, run continuously without software intervention. Acquisition of data from the ADC is primarily a software concern. On completion of each conversion, the AEOC line goes low and is latched by a flip-flop, the output of which is connected to PB1 of the 6805 port B. On detection of this EOC signal the processor accesses the high byte of the ADC data (AENHI), cancelling the flip-flop EOC, and then the low byte of ADC data (AENLO).

ADC data access by the software is essentially asynchronous with respect to the ADC control hardware since the controller must mediate between three separate timebases, the ADC strobe clock, the microprocessor clock and the UART clock. The end-of-set (EOS) and end-of-convert (EOC) inputs to the 6805 are used to ensure transmission of data in the correct order. The following programming sequence provides the synchronisation which is shown schematically in Figure 32.

a) Wait for EOS...last set complete.

b) Wait for NOT EOS...the start of the set.

c) Cancel EOC (read AENHI)...to ensure next EOC refers to channel 1.

d) Wait for EOC.

e) Read AENHI...cancels EOC.

f) Read AENLO.

g) Transmit data to surface.

h) Repeat d,e,f,g for channels 2 - N keeping count in software.

i) Loop to a) for next set.

An alternative mode of data acquisition is used for ancillary data such as the depth and inclination sensors whereby data are accessed at a low rate, typically once per second. In this mode up to eight analogue inputs are sampled in one set following the sequence shown above. On completion of the set the 6805 timer is used to count the EOS signals, alerting the software after N counts (1800 for 1 set/s) to acquire the next set.

2.2.4 Analogue Programming Card

The interface between the controller and the analogue systems comprises three 8-bit latches for the control of gains, signal sources and calibration noise. The latch addresses are decoded from controller lines XA0 and A0 through A3. The bit pattern for each latch for a specific system set-up is interpreted by software from commands transmitted from the surface, see Section 2.4.

Selection of signal source and gain is implemented by setting the appropriate bit pattern into latch XA5 and then setting the required board strobe low (logic '0') for 5 ms minimum. The effect of the selection is dependent on the board selected.

The pseudo random noise generator (PRN) may be configured to produce either a voltage or a current, or switched off (logic '1' = ON in each case). The PRN status is independent of the source selection but to enable a calibration the appropriate source code must be strobed into the desired analogue board.

One bit of the PRN latch is used to switch on power to a pressure sensor and inclinometers (logic '1' = ON). Another is used to switch on power to the compass.

The port addresses for source/gain, board strobes and noise generator/power are given in Table 1.

2.3 Format of Data Transmission

Sixteen bit ADC data are transmitted to the surface via two serial links, one carrying the upper 8-bits of the word, the other carrying the lower 8-bits. Transmission is in groups or SETs of six ADC words, each set being synchronised to the 1800 Hz ADC sampling clock. Each word within the set relates to the data from the ADC multiplexer channel programmed to be active at that position in the sampling sequence.

Referring to the ADC control programming sequences of Section 2.2.3 and to the timing diagram of Figure 32, on recognition by the controller of NOT EOS (start of set) the primary UART transmits a single BREAK character or continuous MARK whilst the secondary UART transmits a continuous SPACE. When the primary UART transmit buffer is empty i.e. the break is in the process of transmission, the controller looks for the first EOC (end of convert) and then accesses (AENHI) the upper 8-bits of the ADC data and (AENLO) the lower 8-bits passing them to the secondary UART and primary UART respectively for transmission. When both transmit buffers are empty the controller repeats the sequence for the next EOC and continues until the programmed number of channels/set have been accessed and transmitted (up to six). On completion of the set, the controller resynchronises by testing for EOS (end of set) and awaits the next NOT EOS starting the next set.

Port address XA5 - source/gain

Bit 0	signal source select 0	SS0
Bit 1	signal source select 1	SS1
Bit 2	signal source select 2	SS2
Bit 3	gain select 1	GS1
Bit 4	gain select 2	GS2
Bit 5	gain select 3	GS3
Bit 6	gain select 4	GS4
Bit 7	gain select 0	GS0

Port address XA6 - board strobes

Bit 0	board strobe 0	BS0
Bit 1	board strobe 1	BS1
Bit 2	board strobe 2	BS2
Bit 3	board strobe 3	BS3
Bit 4	board strobe 4	BS4
Bit 5	board strobe 5	BS5
Bit 6	NC	
Bit 7	NC	

Port address XA7 - noise generator/power

Bit 0	current source X	CALMX
Bit 1	current source Y	CALMY
Bit 2	current source Z	CALMZ
Bit 3	voltage source	CAL1
Bit 4	PRN on/off	CAL0
Bit 5	NC	
Bit 6	compass power	PSW1
Bit 7	pressure/inclin power	PSW0

Table 1: Port addresses

The system is programmed to transmit a specified number of sets followed by a non transmission period of a length equivalent to another specified number of sets. On completion of the transmission period the secondary UART transmits a continuous break character throughout the non transmission period whilst the primary UART transmits a continuous space. The secondary break commences at the same sequence time as the primary break would have started within a set and is cancelled in the EOS period preceding the transmission of the first set of the next transmission period. Prior to the first transmission period the secondary break is transmitted for the equivalent time of 128 set transmissions.

The UART byte transmission format is 1 start bit (mark), 8 data bits, 1 even parity bit, 1 stop bit (space), with a bit clock rate (baud rate) of 153 600 bits/second. A single break character comprises 11 mark bits. A continuous break is a sequence of single break characters without a separating stop bit.

2.4 Controller Programming Commands

Commands are sent to the controller from the surface computer via the serial link. All commands consist of a sequence of alphabetic characters and hexadecimal (0-F) numerals. Characters are not case sensitive but where they are echoed, the echo is in upper case. Note this if an echo checking routine is in operation in the surface transmitter.

Commands recognition routines are incorporated in the EPROM Monitor programme and in the RAM operational program RANGE-V5.C68. The former includes general purpose routines not associated with the application of the controller; the latter includes all the application commands and must be initially downloaded from the surface.

Serial transmission is 4800 baud, 8-bit, 1 stop, no parity.

In the following descriptions, **BOLD** typeface is used for user input transmitted to and echoed by the controller and underlined NORMAL typeface for the controller response. The symbol {CR} is used for carriage return (0Dh), {LF} for line feed (0Ah) and {CRLF} for carriage return plus line feed. Spaces (20h), where not otherwise obvious, are indicated by |.

2.4.1 General Purpose Commands

reset A continuous transmission of BREAK characters for a period exceeding 10 ms will reset the controller regardless of its current activity and status. The primary action of RESET is to clear the UARTs and programme the primary UART for 4800 baud, reverting the software to the basic command recognition status. It does not affect the application parameters currently stored, nor the current status and activity of the analogue systems. The subsequent transmission of a carriage return **{CR}** will cause the controller to respond with the sign on message.

{CR}{LF}
ELFE UNDERWATER SYSTEM CONTROLLER V2.1{CRLF}
!
Controller then awaits a command. ! is the system prompt.
Display memory ...cmd D

The user enters a start address in hexadecimal immediately after D and the Controller outputs the contents of sixteen memory locations in hexadecimal, followed by the ASCII representation of the 16 bytes with a period (.) to represent non-display values. On completion a carriage return will cause the display of the next sixteen locations, or a period (.) will end the routine.

!**D1800{CR}**{LF}
1800 xx xx xx xx xx xx xx xx xx xx xx xx xx xx xx xx ...**{CR}**{LF}
1810 xx xx xx xx xx xx xx xx xx xx xx xx xx xx xx xx ...{CRLF}
!

Memory test ...cmd M

The command M performs non-destructive memory test in the block specified. Locations which failed are reported by address and a hex byte gives the bit by bit error, e.g. a report 0800 03 implies that bits 0 and 1 of memloc 0800 failed.

!M{CR}{LF}
FROM**1700**{CR} TO **1800{CR}** {LF}
1800 FF{CRLF}
DONE{CRLF}
!
(all bits of memloc 1800 failed because it is EPROM, read only)

Substitute in memory ...cmd S

The command S permits alteration of the contents of any RAM location. Enter the address; this is echoed and the current content of that location is output. To change the value enter a new value, otherwise {CR} to leave it unchanged. The next memory location is output similarly. Exit the routine by entering a period (.).

!S{CRLF}
0228{CR}{LF}
0228 FF**CC{CR}**{LF}
0229 FF**18{CR}**{LF}
022A BBOO**{CR}**{LF}
022B 00**{CR}**{LF}
022C A3.
!
(byte sequence was FF FF BB 00 A3, now CC 18 00 00 A3)

Load memory from host ...cmdL

The command L accepts data in a standard format and writes it to an area of RAM. Data are sent in blocks of up to 16 bytes in the following form:
:bbaaaa00CcCcCcCcCcCcFF
where :

bb is no. of databytes in hexadecimal, maximum 10 h (16 decimal)
aaaa is the intended address of the first databyte in hexadecimal
00 is standard
Cc is one databyte in hexadecimal
FF is standard.

The above sequence is repeated as required; all characters between the end of a data block and the subsequent colon (:) are ignored, e.g. carriage return. The data may thus be prepared as an editable file in the host computer, with comments if desired, for automatic downloading to the controller. This format is produced by the compiler COMP68.

The final line ends entry and passes control to the command processor.
:0000000000

Note that the following command is not designed for direct keyboard usage. Nothing is echoed after the initial L command. This command is normally used to transfer operational programmes to the controller.

!**L**{CRLF} (from this point nothing is echoed)
:10080000xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxFF{CRLF} {CRLF} is optional
:0000000000
!

2.4.2 Application Commands

The term CHANNEL refers to the sequence number of data transmitted to the surface within a SET of data[2]. Software recognises channels 01 through 08; however a maximum of six, 01 through 06 may be transmitted at 1800 Hz ADC conversion rate.

---

[2]Not to be confused with the channel number associated with the multiplexer address

'P' commands transfer programming information to the controller but do not actively install them. 'Q' commands install parameters previously passed by the 'P' commands, having carried out a `translation' into the appropriate bit patterns.

Programme multiplexer address ...cmd PMxxyy

This command sets the multiplexer address for channel xx to code yy.

!PMxxyy{CR}{LF}
!

MULTIPLEXER

00h	AMX	AC magnetic field	X axis
01h	AMY	AC magnetic field	Y axis
02h	AMZ	AC magnetic field	Z axis
03h	AEX	AC electric field or Geophone	X axis
04h	AEY	AC electric field or Geophone	Y axis
05h	AEZ	AC electric field or Geophone	Z axis
06h	DCEX	DC electric field	X axis
07h	DCEX	DC electric field	Y axis
08h	DCEZ	DC electric field	Z axis
09h	PRES *	pressure	
0Ah	$+V_X$	excitation for pressure	
0Bh	$-V_X$	transducer and inclinometers	$\Delta V_X = 5$ v nom
0Ch	INCX *	inclinometer	X axis
0Dh	INCY *	inclinometer	Y axis
0Eh	spare		
0Fh	spare		

NOTE: Items marked * require PSW0 ON to enable power to transducers.

Programme source ...cmd PSxxyy

This command sets the source for channel xx to code yy

!PSxxyy{CR}{LF}
!

SOURCE	MUX channels 00h through 02h	AC magnetic
01h	calibration voltage connected to amplifier	
02h	AM coils connected to preamplifier	
03h	preamplifier inputs shorted	
05h	calibration current connected to amplifier	

SOURCE	MUX channels 03h through 05h	AC electric
01h	calibration voltage connected to amplifier	
02h	AE sensor connected to preamplifier	
03h	preamplifier inputs shorted	
05h	geophone connected to preamp	

Programme gain ...cmd PGxxyy

This command sets the gain, preamp and main amp, of channel xx to code yy.

!PGxxyy{CR}{LF}
!

GAIN	MUX channels 00h through 02h	
01h	preamp gain 20 dB, main amp 00 dB	total gain 20 dB
02h	preamp gain 20 dB, main amp 10 dB	total gain 30 dB
04h	preamp gain 20 dB, main amp 20 dB	total gain 40 dB
08h	preamp gain 20 dB, main amp 30 dB	total gain 50 dB
11h	preamp gain 40 dB, main amp 00 dB	total gain 40 dB
12h	preamp gain 40 dB, main amp 10 dB	total gain 50 dB
14h	preamp gain 40 dB, main amp 20 dB	total gain 60 dB
18h	preamp gain 40 dB, main amp 30 dB	total gain 70 dB

GAIN	MUX channels 03h through 05h	
01h	main amplifier 00 dB gain	total gain 40 dB
02h	main amplifier 10 dB gain	total gain 50 dB
04h	main amplifier 20 dB gain	total gain 60 dB
08h	main amplifier 30 dB gain	total gain 70 dB

Programme noise generator ...cmd PNxxyy

This command sets the PRN status for channel xx to code yy.

!PNxxyy{CR}{LF}

!

PRN	
0*h	noise generator off (* = any hex)
1*h	noise generator on
10h	no outputs
11h	noise current to X coil
12h	noise current to Y coil
13h	noise current to X and Y coils
14h	noise current to Z coil
15h	noise current to X and Z coils
16h	noise current to Y and Z coils
17h	noise current to X and Y and Z coils
18h	noise voltage to all main amplifiers

19h through 1Fh = 18h + 01h through 07h

Programme number of channels ...cmd PLxxyy

This command sets the number of channels for transmission in each set to xx. The minimum value of xx is 01 and the maximum is 08, but note the restriction to 6 channels at 1800 Hz conversion rate.
Set yy = xx.

!PLxxyy{CR}{LF}

!

Programme transmission on time ...cmd POxxyy

The software is designed to transmit a programmed number of SETS of data. On completion a second programmed number of sets is counted but not transmitted, to allow the host computer time to offload the data to disk. The sequence repeats until the controller is reset.

This command sets on time to xxyyh SETS at 1800 sets/s :

!POxxyy{CR}{LF}

!

(Note that yy must be 00 for use by RANGE8 version of RANGE-V5.)

Programme non-transmission off time ...cmd PFxxyy

This command sets off time to xxyyh SETS at 1800 sets/s.

!PFxxyy{CR}{LF}

!

(Note that yy must be 00 for use by RANGE8 version of RANGE-V5.)

Install all parameters ...cmd QA

Install the parameters programmed by PM, PS, PG, PN commands for the number of channels specified by the last PL command. The source and gain parameters for each channel are combined, converted to the appropriate bit pattern and placed in the XA5 latch of the Analog Programming Card. This is then strobed into the sensor channel designated for the associated multiplexer address. The noise generator parameters for all the channels are combined. If any noise source is required the generator is switched on; otherwise it is switched off.

!QA

!

Install parameters to specified channel ...cmd Qn

This command installs the parameters programmed by PM, PS, PG commands for the n'th channel, $1 \leq n \leq 8$.

!Qn

!

Programme noise generator and active ...cmd QN

Programme PRN generator with yy and switch on (xx=01) or off (xx=00) power supply PSW0. Note that this does not change the parameters stored by command PN and used by QA and QR.

!QNxxyy{CR}{LF}

!

Install all parameters and run ...cmd QR

This command installs all parameters as for QA and commence acquisition and transmission of data. See Section 2.3 for output format.

!QR

Transmit 8 channels ancillary data ...cmd QD

This command accesses eight ADC multiplexer channels and transmit. Repeat sequence every one second. Cancel by RESET. The ADC channels are preset in the program. The power supply PSW0 is automatically turned on.

!QD{CRLF}
xxx| |xxxx| |xxxx| |xxxx| |xxxx| |xxxx| |xxxx| |xxxx{CRLF}
xxx| |xxxx| |xxxx| |xxxx| |xxxx| |xxxx| |xxxx| |xxxx{CRLF}
etc.

format	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx hexadecimal
mux addr	06	07	08	09	0A	0B	0C	0D
source	DCEX	DCEY	DCEZ	PRES	$+V_X$	$-V_X$	incX	incY

Compass output ...cmd QC

This command switches on the compass (PSW1). Read the compass output string until a string terminator is found, then transmit the next complete string. Switch off the compass.

!QC{CRLF}
$ HCHSC,xxx,M,yyy,T,Z,E{CRLF}
!

where xxx = magnetic bearing in degrees (decimal)
yyy = true bearing in degrees (if correctly offset)

Report parameters ...cmd X

This command reports the parameters programmed by the last PM, PS PG, PN, PF PO, PL commands. Output reflects the input forms. Default values are displayed if a parameter has not been passed.

!X{CRLF}
....report....
!

Test leak warning ...cmd TL

When a leak is detected the software is interrupted with absolute priority. The primary UART transmits a continuous break and the secondary UART a continuous space. This condition may be uniquely monitored at the surface by smoothing UART character transmission. The TL leak warning test simulates a leak (see Section 2.2.1). Cancel by RESET.

!TL

2.5 Programming Notes

Although the commands listed in Section 2.4 may all be used from the keyboard of the host computer, the main application commands are designed primarily for automatic transmission from a host program. Such a programme is the subject of the next section. Other commands are provided for testing, calibration and fault investigation. For this a full understanding of the hardware is essential.

The procedure for initiating a data acquisition may be summarised as follows, all transmissions being echo checked.

(a) RESET the controller.

(b) Transmit the number of channels required, for example, PL0303 for three channels. (Note {CR}s not shown)

(c) Transmit the multiplexer codes for each channel to select the required sensors, for example, PM0100 PM0201 PM0302 for AC magnetic X, Y, Z axes.

(d) Transmit the source codes to select the particular source for each sensor channel, for example, PS0003 PS0103 PS0203 to short the inputs.

(e) Transmit the required gains for each channel, for example, PG0011 PG0211 PG0211 for 40 dB preamp, 0dB main amp gain.

(f) Transmit the noise generator status required for each channel, for example, PN0000 PN0100 PN0200 for PRN completely off.

(g) Transmit the number of sets required in each transmission period, for example, PO8000 for 16384 sets/period.

(h) Transmit the number of sets to be counted between transmission periods, for example, PF0400 for 1024 sets/rest period.

(i) Transmit QR to programme and run. Reconfigure host for data acquisition during initial 128 set delay (see Section 2.3).

(j) To end the data acquisition, RESET.

3. FIVE CHANNEL SERIAL I/O UNIT

The five UART unit is a plug-in card for IBM compatibles which provides five independent serial I/O ports, one of which is used for communicating with the UWP[3], see Figure 33. External connection is via a 37 pin 'D' socket which carries six lines for each port, comprising transmit (TxD) and receive (RxD), two input logic lines (CTS/,DSR/)[4] and two output logic lines (RTS/,DTR/). In addition two lines carry Common, two lines carry +5 volt and one line each for +12 and -12 volts. All I/O lines are 5 volt logic and are driven by or accepted into 74HC244 buffers. All input lines have 100 KW pullup resistors.

---

[3] This unit is also referred to as the ADOBECOM (Acoustic Deep Ocean Bottom Experiment Communications) unit.

[4] In this description, a logic line name followed by '/', as in DTR/, indicates that the line is active low or negative true.

The unit is based on National NSC858 CMOS UARTs operating on a 2.4576 MHz crystal clock. Maximum data rate is 1 Mbaud using a x1 clock factor (limited by UART capability) and 153.6 kbaud using a x16 clock factor (limited by the crystal). The five UARTS may have different baud rates, but for a particular UART, transmit and receive rates are identical.

The unit resides in system I/O space at addresses 02C0h to 02C7h. This may be varied by reconfiguring on board switches, but care must be taken to avoid conflict with other functions. Note that I/O space is only decoded from address bits A9 to A0, limiting the available space.

Each UART has 14 internal registers. Normally access is via a multiplexed address/data bus, the address selecting the register and the data then input or output. For this plug-in card unit this method would use 80 system I/O addresses, which number is not available, particularly not in a contiguous block, because of the restricted system I/O space. Therefore the register selection is passed to all UARTS by writing the register number to address 02C0h. Data are then read from or written to the specific UART at address {02C0h + UART number}. Note that once a register has been selected it remains selected until a new register number is passed to address 02C0h.

Each UART may generate an interrupt request (RTI/) on detecting a variety of programme selected conditions (e.g. Receive buffer full). A combined system interrupt line is generated by the unit but it is not connected to the system interrupt lines. The RTI/ status of each UART may be read at address 02C6h. The (not connected) unit interrupt output may be masked for each UART by writing to address 02C6h. A write (any data) to address 02C7h will cause a hardware master reset of all UARTS.

The power down (PD) pin of each UART is tied to logic '1' (inactive). The DCD/ input pins are tied to logic '0' (active).

3.1 Functions

```
REGISTER_SELECT      equ  02C0h  ;write only
UART_1               equ  02C1h  ;data Rd/Wt
UART_2               equ  02C2h  ;data Rd/Wt
UART_3               equ  02C3h  ;data Rd/Wt
UART_4               equ  02C4h  ;data Rd/Wt
UART_5               equ  02C5h  ;data Rd/Wt
INTERRUPT_MASK       equ  02C6h  ;write
(bit1=`0', enable INTE/ for UART_1, bit 2 for UART_2 etc.)
(bits 0,6,7 don't care)
INTERRUPT_STATUS     equ  02C6h  ;read
(bit=`0', RTI/ active for UART_1, bit 2 for UART_2 etc.)
(bits 0,6,7 don't care)
HARD_MASTER_RESET    equ  02C7h  ;write only, data=don't care
```

The following are register addresses within the UARTS. Further details obtain from the NSC858 data sheet.

```
RX_HOLDING           equ  00h
TX_HOLDING           equ  00h
REC_MODE             equ  01h
XMIT_MODE            equ  02h
GLOBAL_MODE          equ  03h
COMMAND              equ  04h
BAUD_RATE_LO         equ  05h
BAUD_RATE_HI         equ  06h
RT_STATUS_MASK       equ  07h
RT_STATUS            equ  08h
MODEM_STATUS_MASK    equ  09h
MODEM_STATUS         equ  0Ah
POWER_DOWN           equ  0Bh
MASTER_RESET         equ  0Ch
```

3.2 External Connector

UART No	1	2	3	4	5
DSR/	pin 1	7	13	19	25
CTS/	2	8	14	20	26
RxD	3	9	15	21	27
DTR/	4	10	16	22	28
RTS/	5	11	17	23	29
TxD	6	12	18	24	30

COM	36,37
+5v	34,35
+12v	33
-12v	32

3.3 ADOBECOM.ASM

The following is a description of fortran compatible UART subroutines and utilities.

ARGUMENT {uart} is uart number 1 to 5 integer*2
ARGUMENT {parity}{string}{terminator}{charcode} character
ARGUMENT {baudrate}{error}{length} integer*2
{string] must be of sufficient {length}

> subroutine COMSET (parity, baudrate, error, uart)
Initialises UART 8bits, 1stop, N/E/O parity, 300 to 19200 baud
Error = 3 if baudrate unacceptable
Error = 4 if parity not 'N', 'E' or 'O'

> subroutine COMMS (uart)
Display characters received by serial link.
Transmits any character from keyboard.
ESC is only exit from > subroutine.
NOTE: max baud rate 9600 for direct screen print.
NOTE: overrun/parity/frame/break are not checked.

> subroutine TxSTRG (string, length, error, uart)

Transmits {length} characters without echo from {string}

Error = 1 if aborted from keyboard.

> subroutine TxECHO (string, length, error, uart)

Transmits {length} characters contained in {string} via the serial port, receiving and checking the echo after each one.

Error = 1 if aborted from keyboard.

Error = 2 if incorrect echo detected.

Error > 15 if BREAK or parity/overrun/frame error detected.

This error	is sum of	overrun	error	16
	and/or	frame	error	32
	and/or	parity	error	64
	and/or	break	error	256

> subroutine RxSTRG (string, length, terminator, error, uart)

This subroutine accepts a stream of characters into {string} up to and including a termination character (ctrlQ - DC1) or {terminator}. On exit {length} is bytes in {string} excluding terminator.

Error = 1 if aborted from keyboard.

Error > 15 if BREAK or parity/overrun/frame error detected.

This error	is sum of	frame	error	16
	and/or	overrun	error	32
	and/or	parity	error	64
	and/or	break	error	256

> subroutine RXCLR (UART)

Empty the receiver buffer of specified UART.

> subroutine DTRON (UART)

Switch on (active low) DTR output of specified UART.

> subroutine DTROFF (UART)

Switch off DTR output of specified UART.

> subroutine DTRALL

Switch on DTR outputs of uarts 1 to 5 in sequence then switch off.

> subroutine BREAK (UART)

Transmits a continuous BREAK from {uart} until any key is depressed.

> subroutine DxSTRG (string, length)

Displays {length} bytes of {string} on screen.

> subroutine KBCHAR (charcode)

Waits for keystroke and returns code (see Table 2). For keystrokes giving extended codes (00h followed by code), the code has bit 7 set to '1', i.e. extended codes ⇒ 80h.

KEY	DIRECT	SHIFT	CTRL	ALT	KEY	DIRECT	SHIFT	CTRL	ALT
A	61	41	01	9E	Space	20	20	20	20
B	62	42	02	B0	Esc	1B	1B	1B	-
C	63	43	03	AE	Tab	09	8F	-	-
D	64	44	04	A0	Backspace	08	08	0F	-
E	65	45	05	92	Enter	0D	0D	0A	-
F	66	46	06	A1	Insert	D2	D2	-	-
G	67	47	07	A2	Delete	D3	D3	-	-
H	68	48	08	A3	Home	C7	C7	C7	-
I	69	49	09	97	End	CF	CF	F5	-
J	6A	4A	0A	A4	Page up	C9	C9	84	-
K	6B	4B	0B	A5	Page dn	D1	D1	F6	-
L	6C	4C	0C	A6	L arrow	CB	CB	F3	-
M	6D	4D	0D	B2	U arrow	C8	C8	-	-
N	6E	4E	0E	B1	D arrow	D0	D0	-	-
O	6F	4F	0F	98	R arrow	CD	CD	F4	-
P	70	50	10	99	KEYPAD				
					numlock OFF				-
Q	71	51	11	90	.	D3	2E	-	FF
R	72	52	12	93	0	D2	30	F5	-
S	73	53	1	9F	1	CF	31	-	-
T	74	54	14	94	2	D0	32	F6	-
U	75	55	15	96	3	D1	33	F3	-
V	76	56	16	AF	4	CB	34	-	-
W	77	57	17	91	5	35	F4	-	-
X	78	58	18	AD	6	CD	36	F7	-
Y	79	59	19	95	7	C7	37	-	-
Z	7A	5A	1A	AC	8	C8	38	84	-
`~	60	7E	-	-	9	C9	39	-	-
1!	31	21	-	F8	/	2F	2F	-	-
2@	32	40	83	F9	*	2A	2A	-	-
3#	33	23	-	FA	-	2D	2D	-	-
4$	34	24	-	FB	+	2B	2B	-	-
5%	35	25	-	FC	Enter	0D	0D	0A	-
6^	36	2	1E	FD	KEYPAD				
					numlock ON				
7&	37	26	-	FE	.	2E	D3	-	-
8*	38	2A	-	FF	0	30	D2	-	-
9(	39	28	-	80	1	31	CF	F5	-
0)	30	29	-	81	2	32	D0	-	-
-_	2D	5F	1F	82	3	33	D1	F6	-
=+	3D	2B	-	83	4	34	CB	F3	-
[{	5B	7B	1B	-	5	35		-	-
]}	5D	7D	1D	-	6	36	CD	F4	-
\\|		5C	7C	1C	7	37	C7	F7	-
;:	3B	3A	-	-	8	38	C8	-	-
'"	27	22	-	-	9	39	C9	84	-
,<	2C	3C	-	-	/	2F	2F	-	-
.>	2E	3E	-	-	*	2A	2A	-	-
/?	2F	3F	-	-	-	2D	2D	-	-
					+	2B	2B	-	-
					Enter	0D	0D	0A	-
F1	BB	D4	DE	E8	F6	C0	D9	E3	ED
F2	BC	D5	DF	E9	F7	C1	DA	E4	EE
F3	BD	D6	E0	EA	F8	C2	DB	E5	EF
F4	BE	D7	E1	EB	F9	C3	DC	E6	F0
F5	BF	D8	E2	EC	F10	C4	DD	E7	F1

Table 2: Hexadecimal code produced by subroutine KBCHAR...file KBCHAR.VAL.

AMX channel:	AMX	alternating magnetic field sensor, X axis
	CALX	AMX sensor with a calibration noise current injected
	CALI	a voltage proportional to the calibration current
	CALA	noise calibration of amplifier and ADC
	ZERO	AMX sensor replaced by a short circuit
	OFF	data not acquired from AMX channel
AMY channel:	AMY	alternating magnetic field sensor, Y axis
		CALY, CALI, CALA, ZERO, OFF as for AMX channel
AMZ channel:	AMZ	alternating magnetic field sensor, Z axis
		CALZ, CALI, CALA, ZERO, OFF as for AMX channel
AEX channel:	AEX	alternating electric field sensor, X axis (not currently fitted)
	GEOX	geophone, X axis
	CALA	noise calibration of amplifier and ADC
	ZERO	AEX sensor replaced by short circuit
	OFF	data not acquired from AEX channel
AEY channel:	AEY	alternating electric field sensor, Y axis (not currently fitted)
	GEOY	geophone, Y axis
		CALA, ZERO, OFF as for AEX channel
AEZ channel:	AEZ	alternating electric field sensor, Z axis (not currently fitted)
	GEOZ	geophone, Z axis
		CALA, ZERO, OFF as for AEX channel

Table 3: Channel names and sources.

4. ACQUISITION SOFTWARE

4.1 Sources of ELF Data

Data are originally acquired from up to six A/D converter channels in the ELF underwater package. Within the programme these channels are known by the name of the primary sensor attached to them. However the source of data on each channel is selectable prior to each acquisition run. The channel names and possible sources are given in Table 3.

4.2 Format of ELF Data Files

Data are acquired[5] from those channels which are not OFF in BLOCKS of 1024, 2048, 4096, 8192 or 16384 conversions (ONCONS), separated by a number of non acquisition conversion counts (OFCONS)(disk I/O time). The number of BLOCKS is limited only by available disk space.

Each data run produces a data file and a header file. Files are named ELFExxxx.DAT and ELFExxxx.HDR where xxxx is the run number. Data are recorded in both files in binary form and is therefore not directly readable.

4.2.1 Header File

The header file comprises three sections. Section 1 consists of 74 bytes recording the acquisition parameters, including data sources and channel gains. Section 2 contains a 20 byte status report for each block of data, recording user operated event markers and transmission error status. Section 3 comprises a 34 byte record of the last update of ancillary data. A description of the header file format is given in Table 4.

---

[5]See Section 4.3

4.2.2 Data File

All data in the .DAT file are INTEGER*2 binary format and are organised on a block by block basis. Within each block the data are divided into sections, one for each channel of data (up to six channels). Each section contains the contiguous data from the particular channel and is 2*ONCONS bytes long. The sequence of channels is AMX, AMY, AMZ, AEX, AEY, AEZ, but if a particular channel is OFF that section is absent. An example is given below.

ONCONS=2048 (datapoints per block) and AEX channel is OFF

BLOCK 1

Byte 1-4096	2048 AMX data points
Byte 4097-8192	2048 AMY data points
Byte 8193-12288	2048 AMZ data points
Byte 12289-16384	2048 AEY data points
Byte 16385-20480	2048 AEZ data points

BLOCK 2

Byte 20481-24576	2048 AMX data points
etc.	

The file length is given by
total bytes in file = BLOCKS * (ONCONS*2) * No. channels not OFF.

A summary of the useful parameters for the data and analysed fourier transform files (see Section 5.2) is given in Table 5.

4.3 Acquisition Programme

The ELF acquisition programme (ELFE5.exe) is initiated by entering "ELFE5". Prior to commencement of the programme however, it is

necessary to ensure that the programme RANGE-V5.C68 is on the same drive as the ELFE5.exe file. This programme includes certain application commands necessary for the system controller. The initial step in running the acquisition programme is to automatically reset the range, however if the range is not on line, then an error message will appear upon the screen. With the range reset, the operator enters a four digit run number after which a primary menu appears on screen as shown in Table 6. The functions are described in Table 3 and are invoked by pressing the specified function key; no other keys will be recognised by the acquisition programme.

The acquisition programme ultimately provides data from the active sensors in blocks consisting of 1024, 2048, 4096, 8192 or 16384 conversions per block from the A/D converter which are stored in the file ELFExxxx.dat, where xxxx is the four digit run number. Information about the active channels and parameters selected by the acquisition programme, are stored in a header file ELFExxxx.hdr. The function keys appearing in Table 6 are discussed below.

Section 1 - Acquisition Parameters

Byte	Form	Variable	Description
1-2	I*2	DATIM(1)	Date of acquisition - year
3-4	I*2	DATIM(2)	Date of acquisition - month
5-6	I*2	DATIM(3)	Date of acquisition - day
7-8	I*2	DATIM(4)	Time of acquisition - hour
9-10	I*2	DATIM(5)	Time of acquisition - minute
11-12	I*2	DATIM(6)	Time of acquisition - second
13-14	I*2	DATIM(7) = 00	Time of acquisition - 1/100 sec
15-18	I*4	BLOCKS	No of blocks of data in file
19-22	I*4	ONCONS	No of data points per block
23-26	I*4	OFCONS	No of data points between blocks
27-31	I*4	PARAMS(1,1)	AMX source selection
32-35	I*4	PARAMS(2,1)	AMX gain selection
36-74	I*4	PARAMS(1,2) to PARAMS(2,6)	for remaining channels

Section 2 - Status Report

Report for 1st BLOCK, commences at byte 74+

Byte	Form	Variable	Description
1-2	I*2	REPORT(1,1)	Datapoint at event marker detection
3-4	I*2	REPORT(2,1)	Mark code at report(1,1)
5-6	I*2	REPORT(3,1)	Datapoint at event marker detection
7-8	I*2	REPORT(4,1)	Mark code at report(3,1)
9-10	I*2	REPORT(5,1)	Datapoint at event marker detection
11-12	I*2	REPORT(6,1)	Mark code at report(5,1)
13-14	I*2	REPORT(7,1)	Datapoint at event marker detection
15-16	I*2	REPORT(8,1)	Mark code at report(7,1)
17-18	I*2	REPORT(9,1)	No. of datapoints received in block
19-20	I*2	REPORT(10,1)	No. of errors detected in block

Report for 2nd BLOCK, commences at byte 94+

Byte 1-20 REPORT(1,2) to REPORT(10,2)

Section 3 - Ancillary Data

Commences at byte 74 + 20*BLOCK +

Byte	Form	Variable	Description
1-14	I*2	AUXTIM(1)-(7)	Date/time...see DATIM above
15-18	R*4	VREF	Reference voltage (volts)
19-22	R*4	DEPTH	Pressure sensor (metres)
23-26	R*4	INCLX	Inclinometer X axis (degrees)
27-30	R*4	INCLY	Inclinometer Y axis (degrees)
31-33	R*4	BRG	Compass bearing (degrees magnetic)

Table 4: Header file structure.

nfft	2^{10}	2^{11}	2^{12}	2^{13}	2^{14}
blocksize	1024	2048	4096	8192	16384
acquisition time/sec	0.57	1.14	2.28	4.55	9.10
null blocks: size	512	512	1024	2048	2048
null blocks: time	0.28	0.28	0.57	1.14	1.14
acquisition/null ratio	2:1	4:1	4:1	4:1	8:1
frequency span/Hz	900	450	225	112	56
frequency resolution Δf/Hz 1.76	1.76	0.88	0.44	0.22	0.11
FT files	FT1	FT2	FT3	FT4	FT5

Table 5: Data acquisition and analysis file characteristics.

ELFE RANGE DATA ACQUISITION PROGRAM V5.1

F1	AMX	CALX	CALI	CALA	ZERO	OFF	sF1	20	30	40	50	60	70
F2	AMY	CALY	CALI	CALA	ZERO	OFF	sF2	20	30	40	50	60	70
F3	AMZ	CALZ	CALI	CALA	ZERO	OFF	sF3	20	30	40	50	60	70
F4	AEX	GEOX	-	CALA	-	OFF	sF4	40	50	60	70	-	-
F5	AEY	GEOY	-	CALA	-	OFF	sF5	40	50	60	70	-	-
F6	AEZ	GEOZ	-	CALA	-	OFF	sF6	40	50	60	70	-	-

F7 Conversion/block: 1024 2048 4096 8192 16384

F8 Transmit new parameters to the range

F9 Commence data acquisition

cF9 On-line analysis (not recorded)

SELECT FUNCTION

sF9 Get ancillary data from range

F10 Direct communication with the range

END Exit from the programme

Table 6: Main menu

F1-F6 These function keys enable the selection of a data source for the various channels described in Table 3. Data is acquired from the six A/D converter channels, which are known by the name of the primary sensor attached to them. When this key is pressed, the source selected will be written in reverse video.

sF1-sF6 The shift function keys allow the selection of the gain settings (20 dB to 70 dB) for the source. The selected gain is again written in reverse video.

F7 This function selects the number of conversions per block (ONCONS) for data acquisition. Note that ONCONS is the same for **all** A/D converter channels. The selection is again written in reverse video.

F8 Once the settings for the source and gain, and the number of conversions per block have been chosen, the 'F8 Transmit new parameters to the range' part of the menu will be displayed in bright yellow. This is to signify that the transmission of these settings to the range **must** be the next step. No other keys will be recognised, except 'END' which will exit the user from the programme. Once this has been done, the operator may continue to choose the required function. Should any of the above parameters be changed, it will be necessary to transmit the new setting to the range.

F9 This option commences the acquisition of data to the default drive. Before doing so, the filename of the file to which the data will be written (elfexxxx.dat), the available space on the output disc, the maximum number of blocks that can fit in this space, and the expected number of sets per block are displayed.

cF9 This control function key allows the on-line acquisition and analysis of data. When this key is selected, the operator is presented with a secondary menu, which allows for the selection of a particular data source with its corresponding gain and conversions per block. Once these parameters have been chosen, one block of data only is acquired, analysed, and then displayed graphically upon the screen. This data is not stored. The secondary menu appears as shown in Table 7.

sF9 This key accesses the ancillary data from the range. This includes compass readings, values from the inclinometers, and the depth from the pressure transducer.

F10 This function allows direct communication with the range. The operator is presented with a secondary menu as follows :

Direct communication with the Range

F1 Keyboard.......ESC to exit
F2 Transmit program to Range
F3 Reset the range
F4 Test leak detector

END Exit to main menu

SELECT:

where the function keys F1...F4 are defined as follows :
[F1] This enables various commands to be sent to the controller via the serial link. The recognition of these commands is based upon routines in the EPROM and in the programme RANGE-V5.C68.

These commands consist of a sequence of alphabetic characters and hexadecimal numerals. For more detail on these commands refer to Section 2.4.

[F2] Transmit programme RANGE-V5.C68 to Range or any other programme written in 6805 assembler language (with a .C68 filename extension). This may be required if one wishes to modify certain application commands for the system controller.

[F3,F4] These keys are self explanatory.

[F4] When this key is pressed, a shrill `beep' will be heard if the leak detector is operational.

ELFE RANGE ON-LINE ANALYSIS ROUTINE

F1	AMX	CALX	CALI	CALA	ZERO	OFF	sF1	20	30	40	50	60	70
F2	AMY	CALY	CALI	CALA	ZERO	OFF	sF2	20	30	40	50	60	70
F3	AMZ	CALZ	CALI	CALA	ZERO	OFF	sF3	20	30	40	50	60	70
F4	AEX	GEOX	-	CALA	-	OFF	sF4	40	50	60	70	-	-
F5	AEY	GEOY	-	CALA	-	OFF	sF5	40	50	60	70	-	-
F6	AEZ	GEOZ	-	CALA	-	OFF	sF6	40	50	60	70	-	-

F7 Conversions/block: 1024 2048 4096 8192 16384

END to exit to the main menu

Select the source channel to be analysed

Table 7: Secondary menu.

5. ELF ANALYSIS SOFTWARE

5.1 Introduction

The analysis software is an independent programme which accesses data that have been stored on disk by the acquisition software, or has been recovered from an archive storage medium such as a streaming tape. The software allows the user to analyse the *time domain* data, i.e. the data originally acquired from the sensors, into the *frequency domain* by means of a Fast Fourier Transform (FFT) and to examine the resulting information through full screen graphic displays.

Operation of the programme is guided by substantially self explanatory menus from which actions are selected by use of function keys. Internal checks are provided throughout the programme to prevent destructive or inadmissible actions.

The programme is designed to be run on 'IBM Compatible' computers under MSDOS with 80x87 coprocessor and EGA display. On 10 MHz machines the processing rate is subjectively a little slow although not unacceptable. The use of 20 MHz machines improves the rate to the extent that the operator is not distracted by processing or graphic display delays.

A hard copy of any plot displayed on the screen may be produced by 'screen dump'. A graphics cursor allows the extraction of specific numeric data.

Reference should be made to Sections 4.1 and 4.2 for the descriptions of the data and header file formats and of the definitions and implications of the various available sensors and channels.

5.2 Analysis

The primary identifier for all data files is the four digit run number. In order to analyse the data from a particular run number (xxxx), two files must be available, the data file ELFExxxx.DAT and the header file ELFExxxx.HDR. They must be on the same disk drive/sub-directory, but any disk drive may be used.

The analysis programme recovers information from the header file to enable interpretation of the data file. The data sources and gain settings are displayed **exactly** as in the acquisition software when these parameters were selected. The user specifies a particular channel to be analysed.

The time domain data relating to the selected channel is processed in consecutive samples of N conversions (selectable from 1024 to 16384). The time domain data, which is the output of the 16 bit A/D converter in the underwater unit, is converted from integer to real number form; in the process the values are converted to represent voltage at the A/D converter input. The maximum absolute integer number is also determined to facilitate input overload flagging. The data is then passed through a Hanning window and processed by a Cooley-Tukey radix 8 FFT algorithm.

The output of the FFT operation is (N/2 + 1) complex numbers representing the amplitudes and phases of the sinusoid frequency domain components. Phase information is discarded at this point although additional software could readily be produced if considered of value. The real and imaginary FFT
outputs for each frequency line are combined to produce a final output value which is the mean power of the component sinusoid at that frequency, as measured at the A to D converter input. The lowest frequency is 'DC' and the highest is 900 Hz, half the conversion rate (1800 samples/second). Intermediate frequencies are linearly spaced between these two limits, see Table 5.

When each sample of N conversions has been processed it is stored to a disk file. The file name automatically created for this output has a format which specifies the run number, the sample length (N) and the channel; e.g. file FT3-xxxx.AMX is the output from an analysis of the AMX channel from data file ELFExxxx.DAT, using a 4096 conversion sample length for each FFT. (FT1=1024, FT2=2048, FT3=4096, FT4=8192, FT5=16384). The user may specify any available disk drive to receive the frequency domain data file.

During the processing, the block number being processed is displayed on the screen; if an A/D converter input overload has occurred this fact will be noted on the screen. Alternatively the user may select graphic display during processing, whereby the power spectrum of each FFT sample is displayed in full screen graphics whilst the next sample is being processed.

The plot shows the spectral level in decibels of 513 of the frequency lines from 'DC' upwards. The decibel display range is 90 dB. The maximum displayable level is auto ranged to the nearest 10 dB above the maximum level in the spectrum. The displayable number of lines is limited to 513 by the number of screen pixels included within the plot axes. With a sample length of 1024 conversions, the full frequency range of 'DC' to 900 Hz is shown. With a sample length of 16384 conversions, 'DC' to 56.25 Hz is displayed. Note that all frequency lines are calculated and filed; they may be accessed in the REVIEW mode.

The display also shows the maximum absolute level of the time domain waveform in decibels relative to 1 volt at the A/D converter input (maximum is approx 20 dB). If the A/D converted level reaches the maximum positive or negative value, the plot is overprinted "OVERLOAD".

Processing may be interrupted by a keyboard entry. A cursor is then displayed which may be driven to any frequency line on the plot. The frequency and level of the line are numerically displayed.

5.3 Review

Once time domain data have been analysed and stored in an FT file, it may be recovered for more detailed examination by selecting the REVIEW mode. Having specified the run number the header file is accessed. This file will be sought both on the designated time domain disk drive and the designated frequency domain disk drive. The data source and gain settings are displayed for the run number. The user selects the channel to be reviewed; 'Channel available' or 'Channel not available' will be displayed depending on whether appropriate FT files exist. Similarly the user selects the FFT sample length and will be advised whether the FT file exists.

When the channel and sample length for review have been established the full screen graphic display mode is entered. The display is similar to that shown during the Analyse phase, except that the cursor is automatically displayed with numeric frequency and level readout. Note that time domain signal level information is not available in Review, and that input Overload will not be flagged.

Additional functions are detailed in a HELP overlay which can at any time be displayed at the user's request. The user may move forwards or backwards through the FFT samples or jump to a particular block. The frequency band for display may be specified allowing access to the full frequency range of the spectrum; 513 lines may be displayed in any one plot. The decibel axis is not auto ranging as in the Analyse phase but may be set in 10 dB steps.

A particular feature is that at any frequency specified by the cursor position, a secondary plot may be called up showing the variation of spectral level with time for the full duration of the original data acquisition.

The power spectral levels are normally referenced to the A/D converter input. If the data refer to measurements made with the AC Magnetic sensor coils the user may, before entering the display mode, select a calibrating function to be applied to all plots. In order to do this, coil calibration data in terms of volts/nanotesla at various frequencies must be

supplied on a disk file. The user need only specify the coil number. The display data is adjusted to incorporate the calibration which is calculated from the disk file information by interpolation to the appropriate FFT line frequencies. The calibration factors comprise a single value applicable to all frequencies and an adjustment for each frequency. The base calibration value is displayed and the decibel axis is then referred to this.

It should be noted that a simple software upgrade could allow the spectrum to be displayed in terms of energy or energy density should this be considered desirable.

5.4 Computer Requirements

The analysis programme was originally developed on an NEC APCIV Powermate 2 incorporating 640 kbyte main memory, hard disk, EGA screen, 80286/80287 processors, 10 MHz clock. It has since been run on a COMPAQ PORTABLE III with VGA (EGA mode) screen at 16 MHz clock, on an IBM PS/2 and on an NEC APCIV Powermate 386/20, all using 80386/80387 processors.

In principal the programme should operate on any 'IBM compatible' having a hard disk and EGA screen. However slow clock rates, 8086/8088 processors or lack of coprocessor are likely to cause unacceptable operating times. The hard disk is essential in order to handle the data file sizes although the requirement is not intrinsic to the programme.

The programme operates under MSDOS V3.1 or later. Additional device drivers must be loaded when the computer is booted. ANSI.SYS is required to provide standard ESCape screen functions. The graphics operations are provided by the GSS*CGI product 'Graphics Development Toolkit' from which GSSCGI.SYS and IBMEGA.SYS are required, plus DRIVERS.EXE to initialise the two device drivers.

Internally the programme is written in MS-FORTRAN V4.1. Three in-house custom libraries, XTRAIO11.LIB, BIO21.LIB AND GRAPHX32.LIB are incorporated to provide extended keyboard and screen functions, disk I/O and extended graphics capability respectively. The GSS*CGI library FORCGI.LIB is also required. All subroutines and functions, whatever the source, are Fortran V4 compatible.

5.5 Processing Functions

5.5.1 Hanning Window

The window function is expressed as

$PF \times \frac{1}{2}\{1\text{-}\cos\frac{2\pi(j\text{-}1)}{(J\text{-}1)}$ where the FFT sample contains J A/D converter conversions, $1 \leq j \leq J$ and PF is the Processing factor (= 2).

The Processing factor is included to ensure that the windowed time domain data has the same total energy as the original data prior to windowing. Clearly the total energy in the frequency domain as calculated from the FFT spectrum is the same as that in the unwindowed time domain FFT sample, for a single frequency constant amplitude sinusoid.

5.5.2 Fast Fourier Transform

A time domain FFT sample of J conversions, written as (F(j)), $1 \leq j \leq J$, may also be expressed as the sum of $(J/2 + 1)$ sinusoids at equally spaced frequencies between (and including) 'DC' and half the sampling rate, such that

$$F(j) = \frac{1}{J}\left[A_o + \sum_{n=1}^{J/2} 2\sqrt{A_n + B_n}\,\sin(2\pi nj/J + \phi)\right]$$

$$\sin\phi = \frac{A_n}{A_n^2 + B_n^2}$$

$$\cos\phi = \frac{B_n}{A_n^2 + B_n^2}$$

The algorithm used for the transform [3] calculates the values A_o, A_n and B_n using a reduced version of the original Cooley-Tukey algorithm adapted for real valued time domain input. The frequency of each component sinusoid is (n x F_{conv}/J) where F_{conv} is the sampling rate, $0 \leq n \leq J/2$.

5.5.3 Power Spectrum

From the transform definition, the amplitude of each sinusoid or peak deviation of the sine wave is $A_{peak}(n) = (2/J\ \sqrt{A_n^2+B_n^2}$ and the RMS and the RMS amplitude is $A_{rms}(n) = A_{peak}(n) / \sqrt{2}$. The mean power, P_{mean}, is given by A_{rms}, *i.e.* $2(A_n^2+B_n^2) / J^2$ The DC component of the mean power P_{dc} is a mean value without requiring the root mean square, thus $P_{dc}=A_0^2 / J^2$.

These expressions for mean power are the spectral levels comprising the power spectrum of the time domain sample and it is these values that are stored to the disk file. They are calibrated in terms of volts squared at the A/D converter input.

5.5.4 Energy Spectrum

Energy spectral levels are not computed in the current version of the programme. To obtain energy from power it is necessary to multiply by the time duration of the sample, which is $\frac{J}{F_{conv}}$ It is sometimes convenient to relate spectral levels to a standard bandwidth of 1 Hz, referred to as the spectral density. The power spectral density is identical to the energy spectral level. To obtain the energy spectral density, the levels must be divided by the bandwidth of each spectral line which is again $\frac{J}{F_{conv}}$

5.6 Operating Instructions

Having ensured that all resident auxiliary software has been loaded, the programme is initiated by entering the programme name at the standard MSDOS prompt. The programme file name is ANALxx.EXE where xx is the version number. The ".EXE" is not entered at run time. A main menu

will be presented on the screen, as shown in Table 8. The **F** numbers on the left hand side refer to function keys on the keyboard, as does **END**. To access an option, press the appropriate key. The options menu is redisplayed and may be changed on completion of each activity.

ELFE ANALYSIS PROGRAM V3.1

INITIALISATION OPTIONS

F1	Change disk drive for TIME data	(E:)
F2	Change disk drive for FFT data	(G:)
F3	Change the ELFE run number	(0000)
F4	Show directory of all ELFExxxx.DAT files	
F5	Display FFT after each sample	(NO)
F8	REVIEW existing FREQUENCY DOMAIN data	
F9	ANALYSE TIME DOMAIN data to FREQUENCY DOMAIN	
END	Exit from program	

Table 8: Main menu for ELF analysis program.

F1 Allows the user to advise the programme of the disk drive location of the data and header files that are to be analysed. The drive must have been previously set to the appropriate path if applicable since there is no provision for path changing within the program.

F2 Similarly, this allows the user to advise the programme of the disk drive to which analysed data is to be directed, or from which data is to be reviewed. Note that in **REVIEW** mode the header file may be on either of these drives.

F3 Selects the run number xxxx to be analysed or reviewed.

F4 Displays a directory of all the time data files on the disk drive selected at **F1**.

F5 This key is applicable in analysis mode, selecting graphic display after every FFT sample (YES) or no graphics (NO).

F8 Enters the **ANALYSIS** mode for the run number selected at **F3**.

F9 Enters the **REVIEW** mode for the run number selected at **F3**.

END Exits the programme in an orderly manner, closing all files and clearing the screen.

5.6.1 Analysis Mode

In the initialisation options, select the time data source disk (**F1**), the frequency data destination disk (**F2**), the ELF run number (**F3**) and whether graphics are required (**F5**). Press key **F9** to enter the analysis mode.

References

[1] Vrbancich, J. (1987). *Air-core induction coils; alternating magnetic field sensors* (Report MSD-TN-4/87). Sydney, NSW: Weapons Systems Research Laboratory.

[2] Vrbancich, J. and Scott, L. (1991). *Preliminary observations of ELF vertical magnetic fields from ship sources* - in preparation.

[3] Bergland, G.D. and Dolan, M.T. (1980). *Fast fourier transforms in Programs for Digital Signal Processing.* Ed. Digital Signal Processing Committee, IEEE Press.

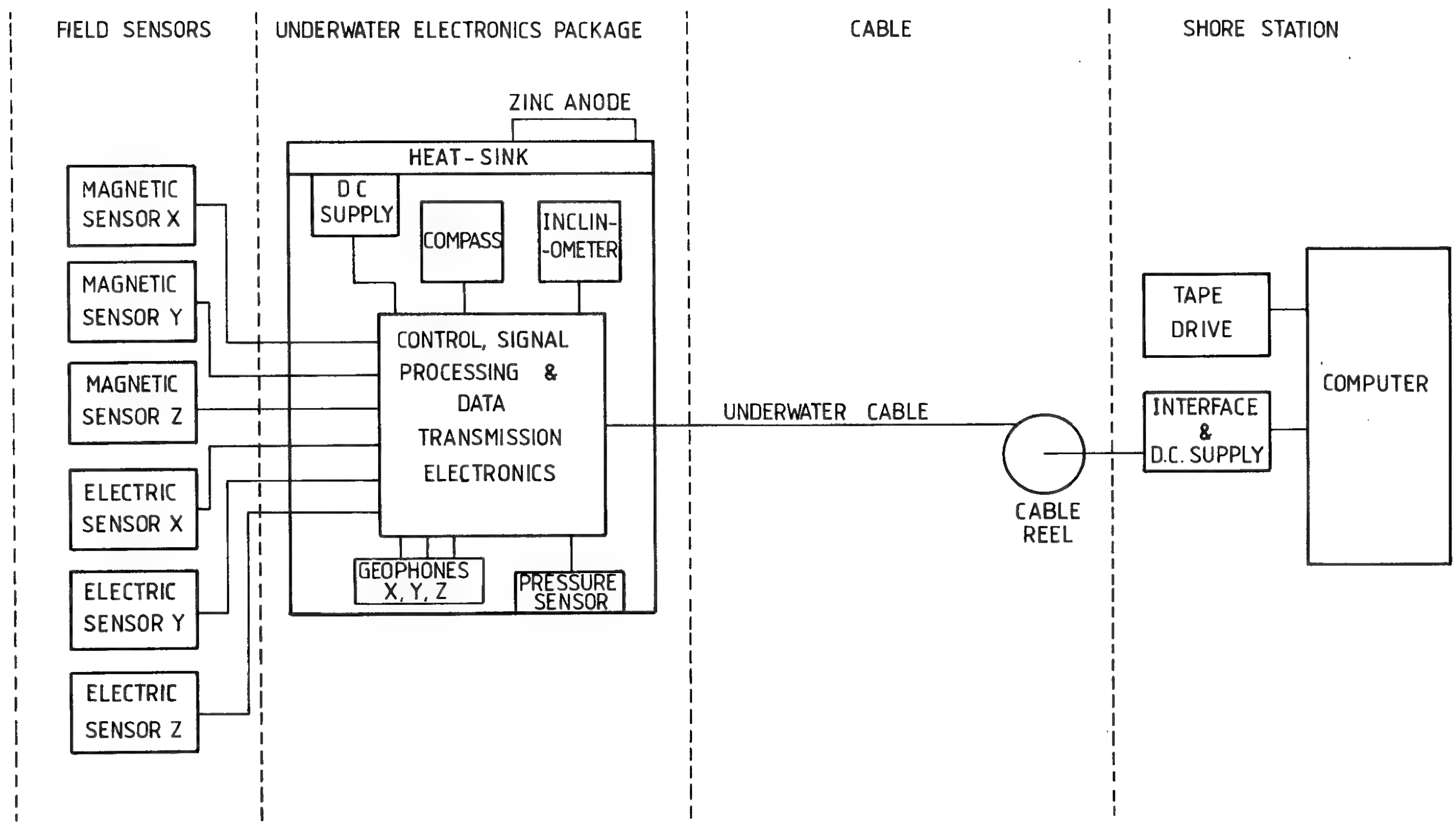


Figure 1: Schematic overview of electrical and electronics hardware.

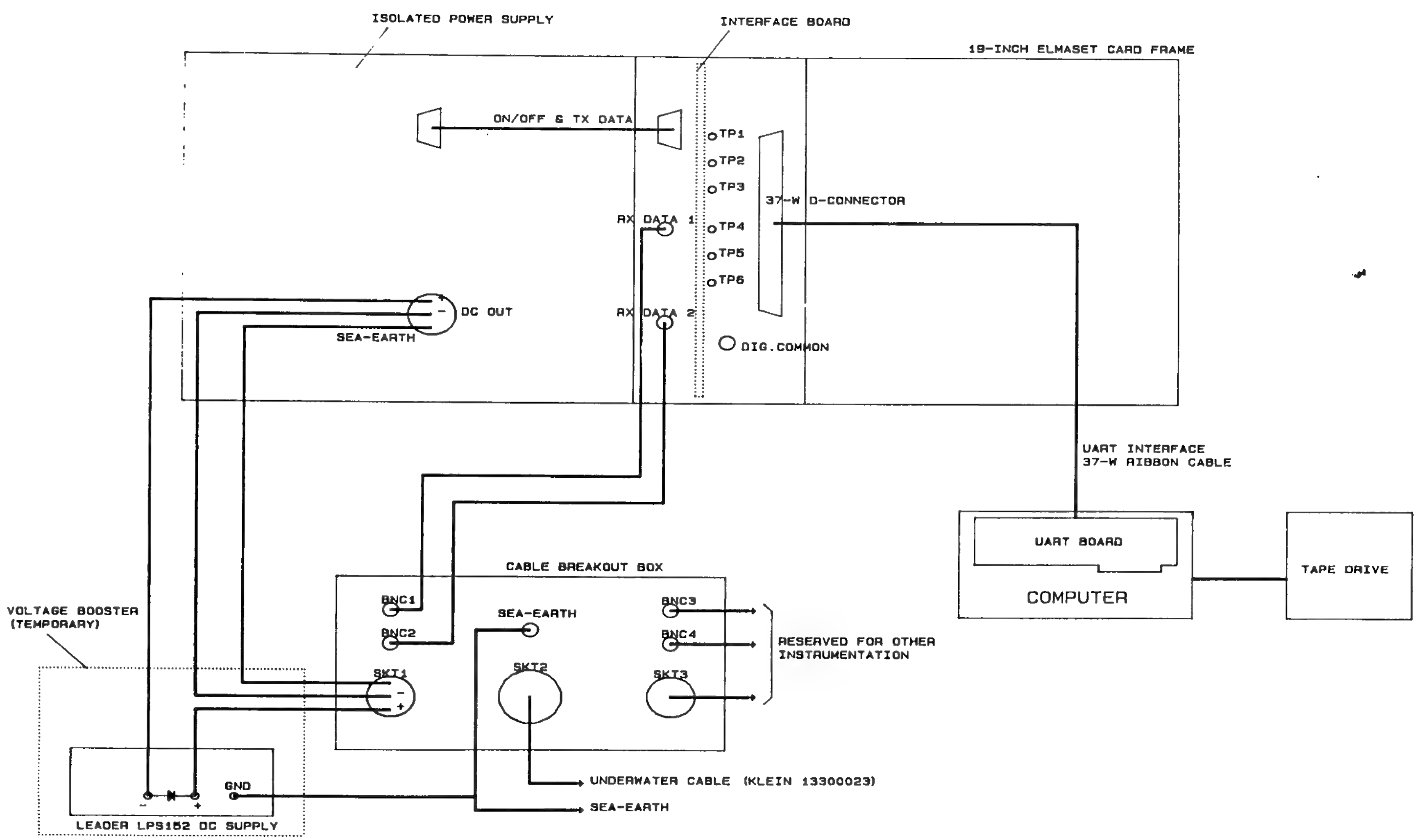


Figure 2: Shore station interface unit.

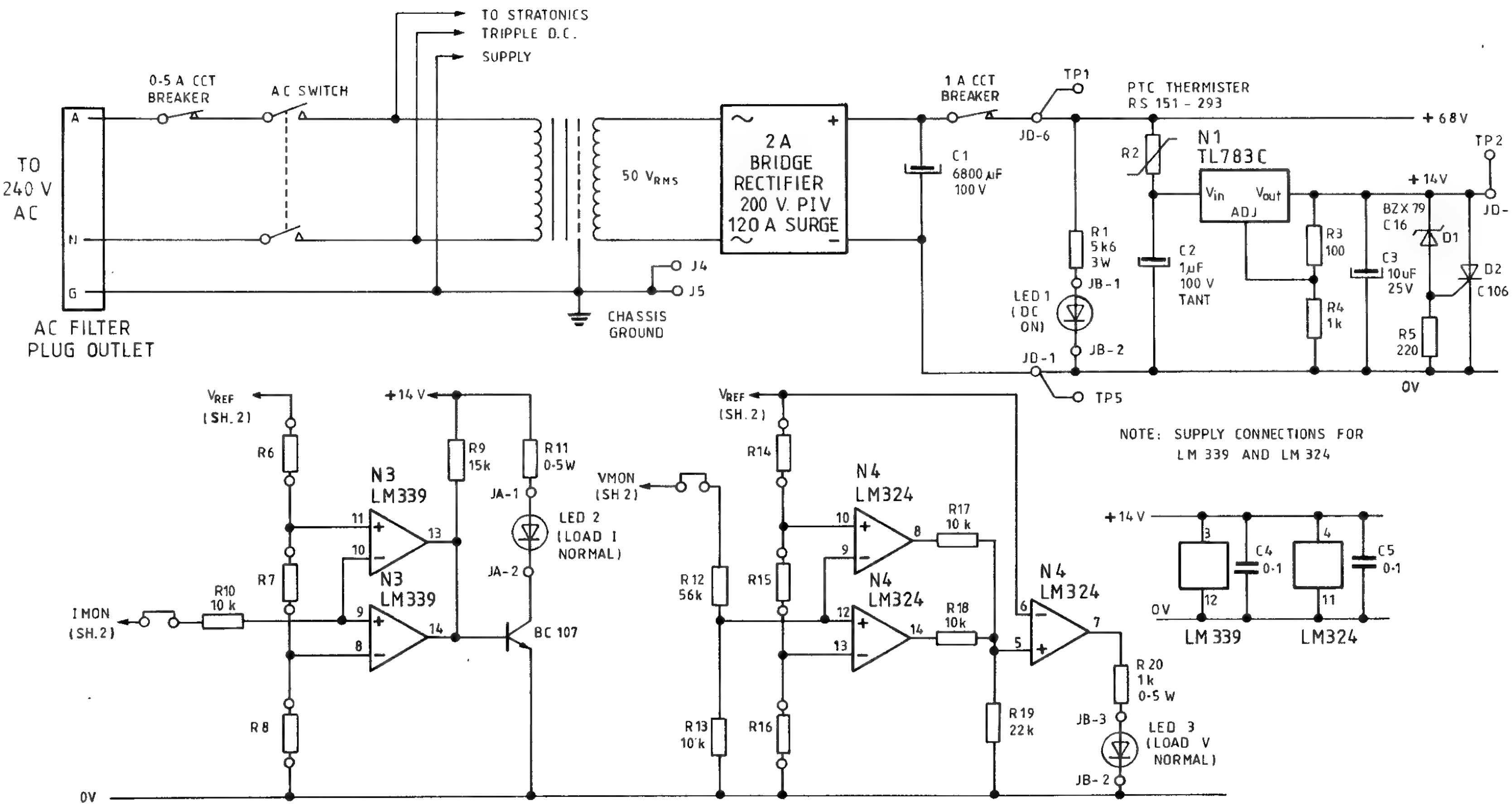


Figure 3: Isolated power supply for shore station.

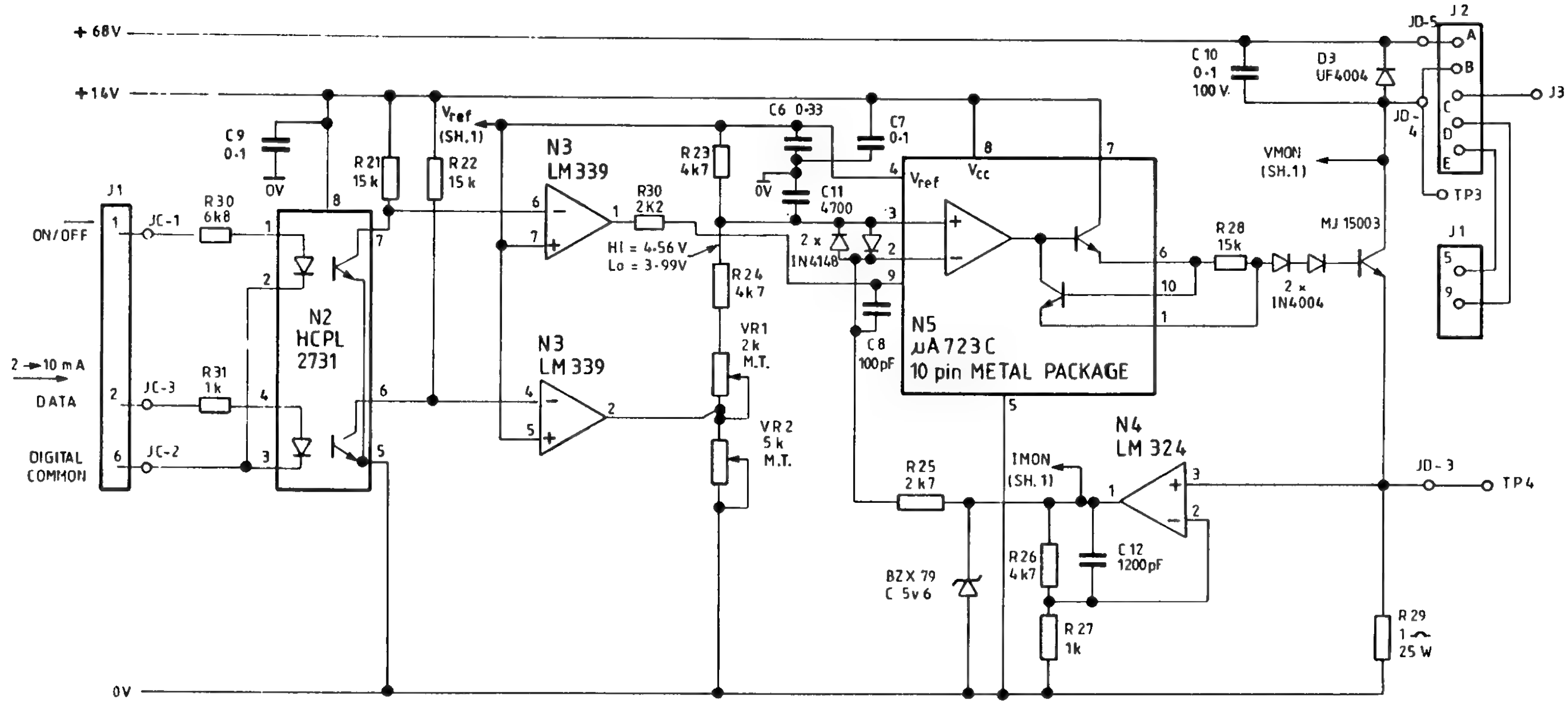


Figure 4: Isolated power supply for shore station, continued.

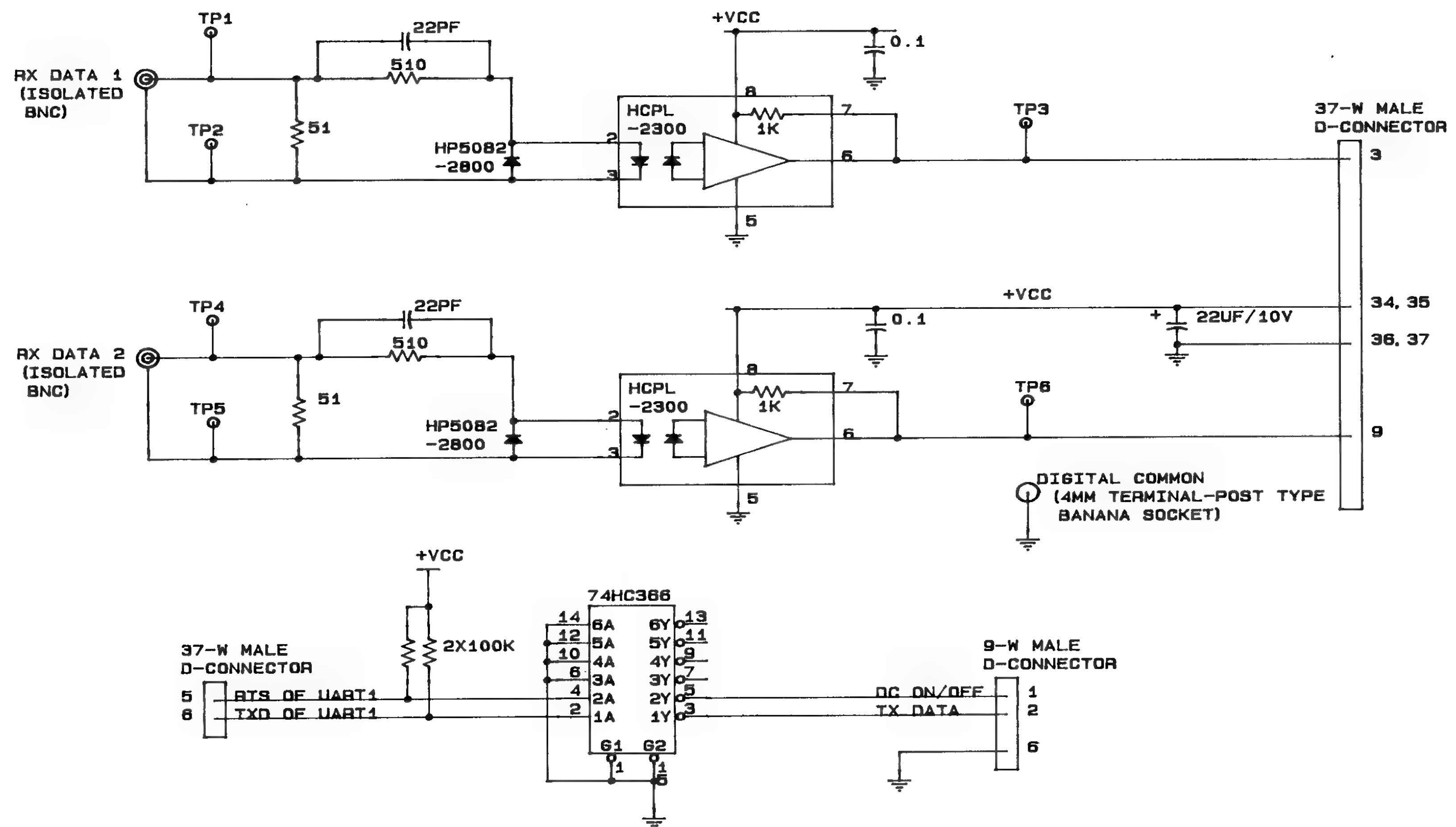


Figure 5: Shore station interface board

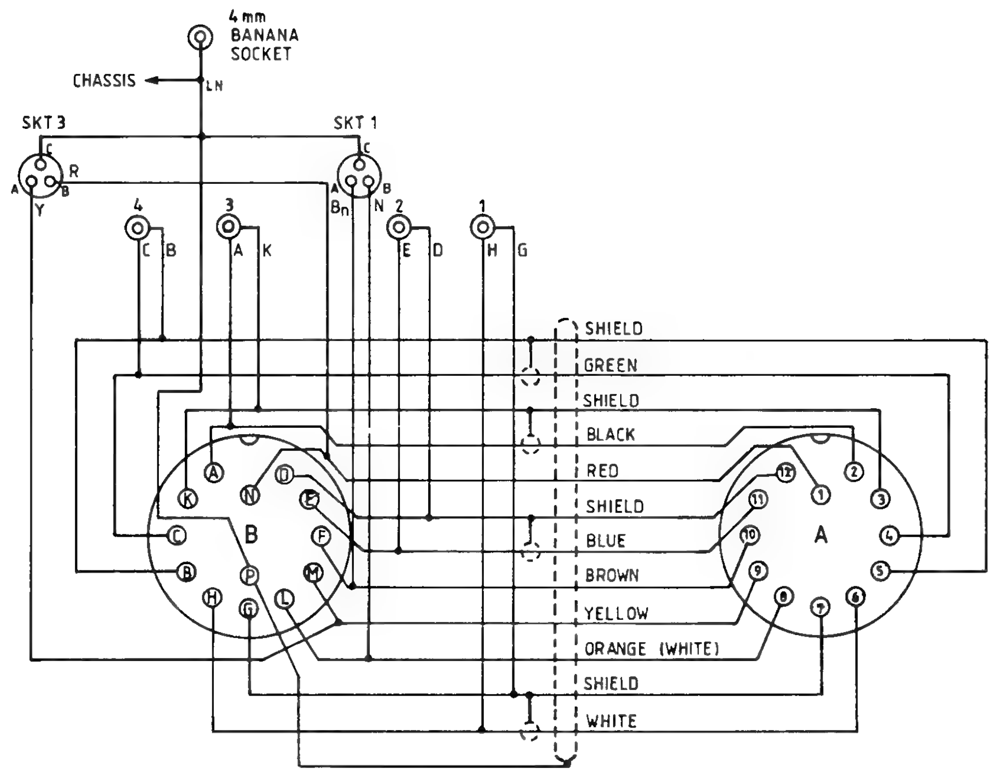


Figure 6: Pin connections for the underwater cable. Pins 1-12 (N...A) are male (female) viewed facing the connecting end of the connector.

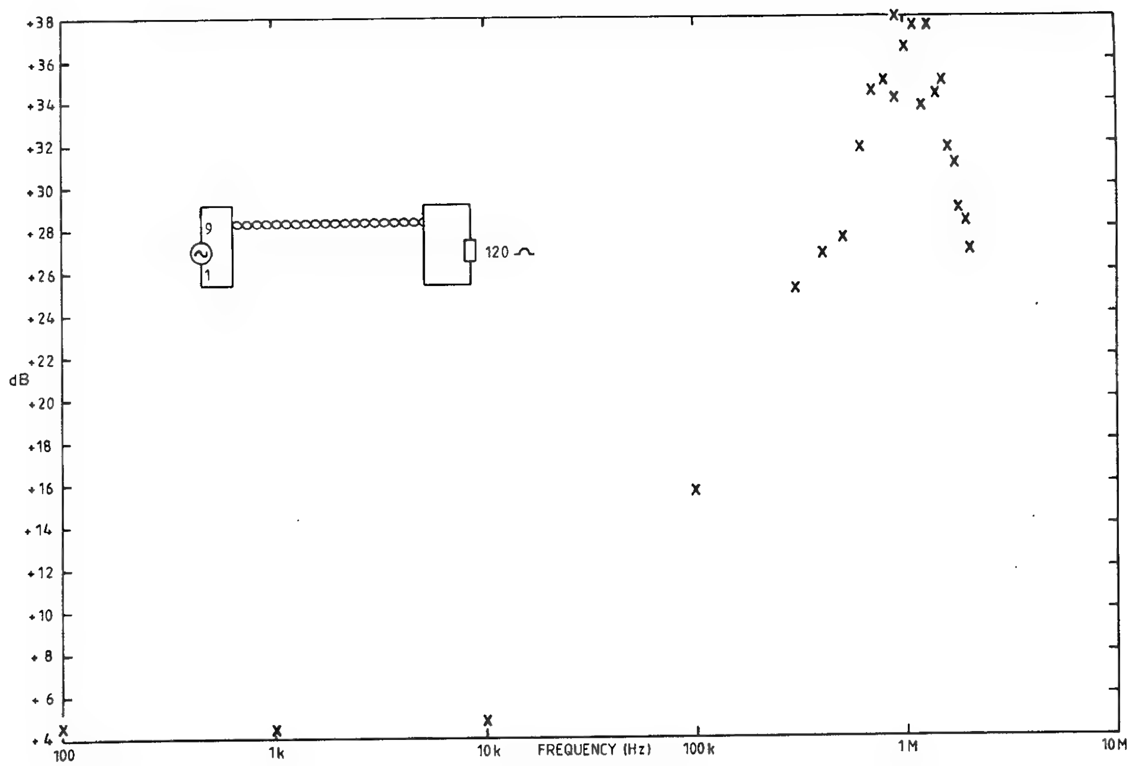


Figure 7: Attenuation as a function of frequency for 870 m of Klein underwater cable from pins 1 and 9, red/yellow twisted pair. (Other twisted pair is orange, #8/brown, #10).

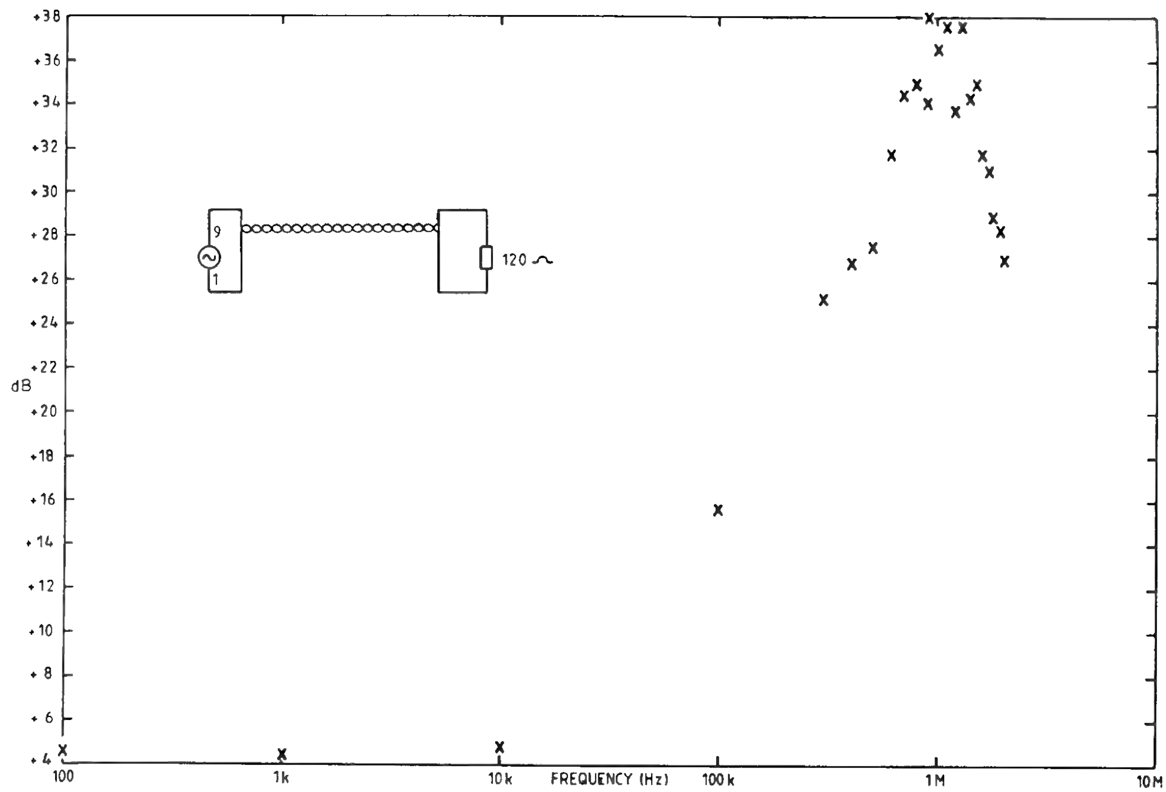


Figure 8: Attenuation as a function of frequency for 870 m of Klein underwater cable from pins 2 and 3, black coaxial line. (Other coaxial lines are #2/#3, #4/#5/, #6/#7 and #11/#12).

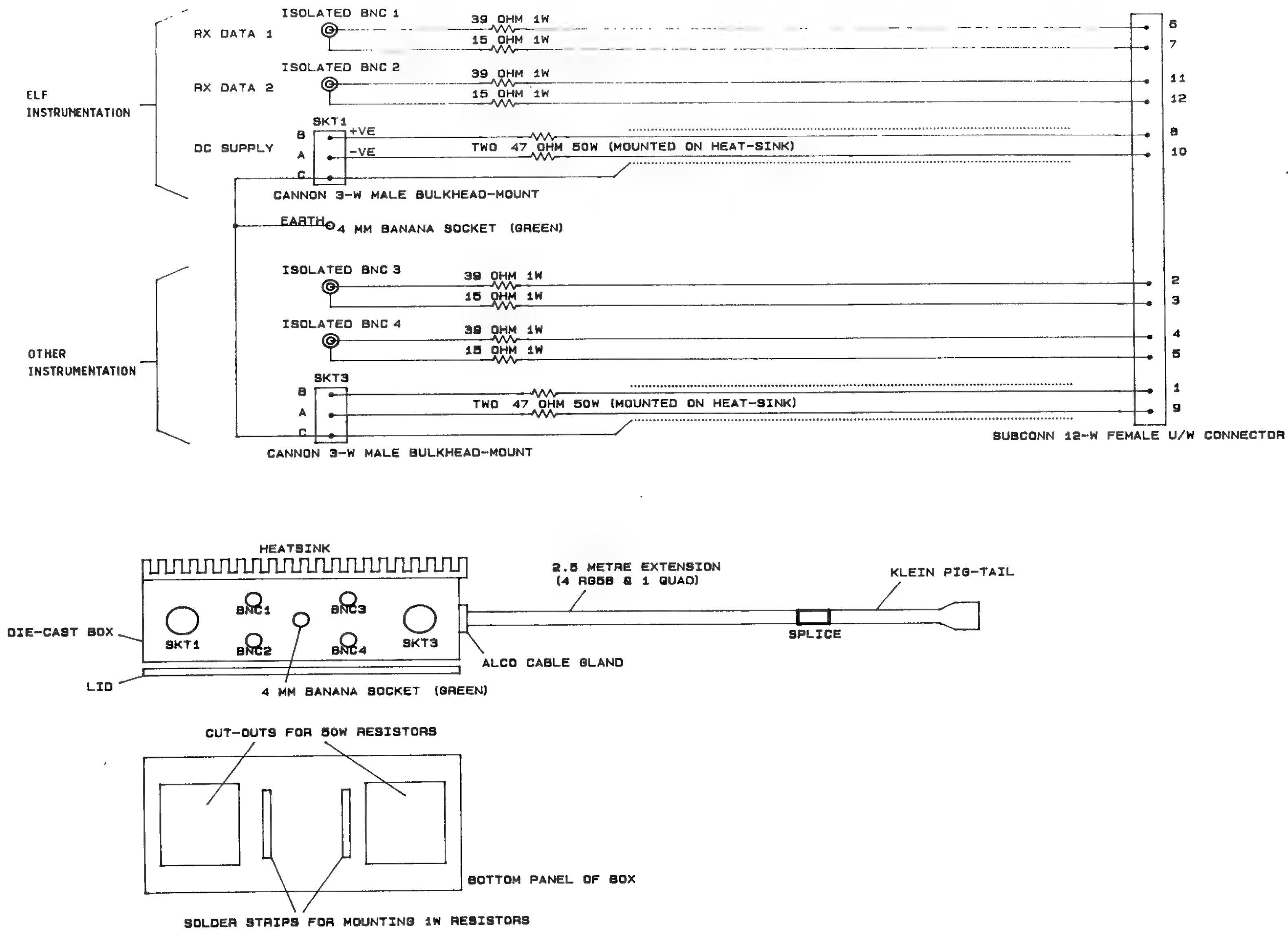


Figure 9: Substitution box for emulating the 870 m of Klein cable.

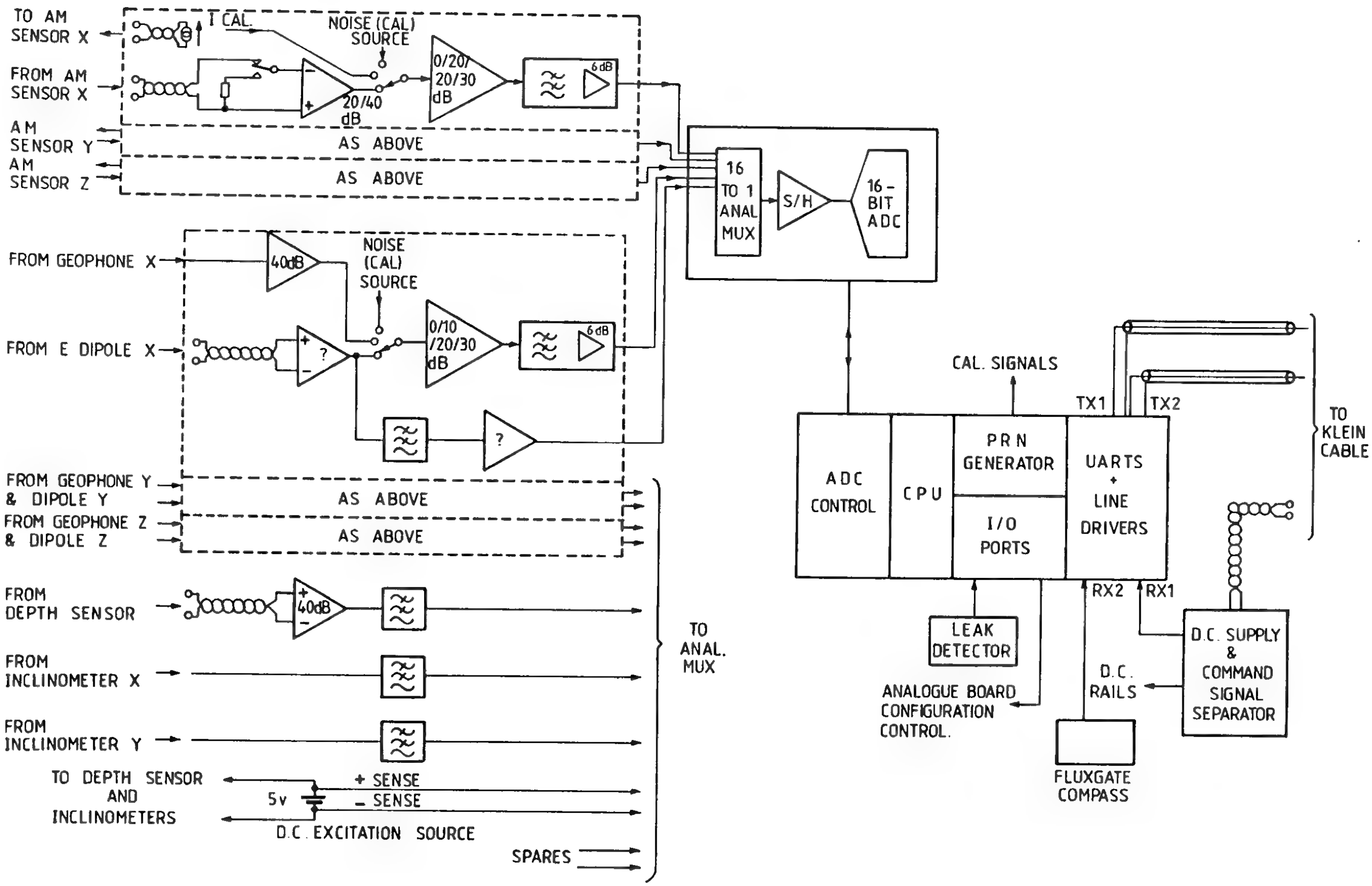
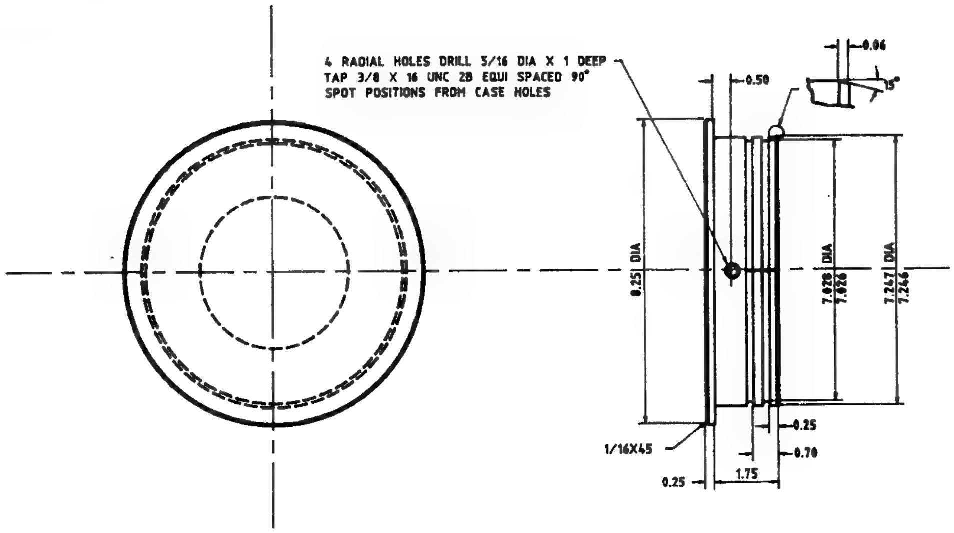
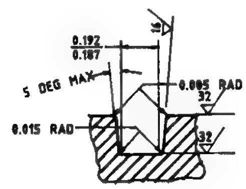


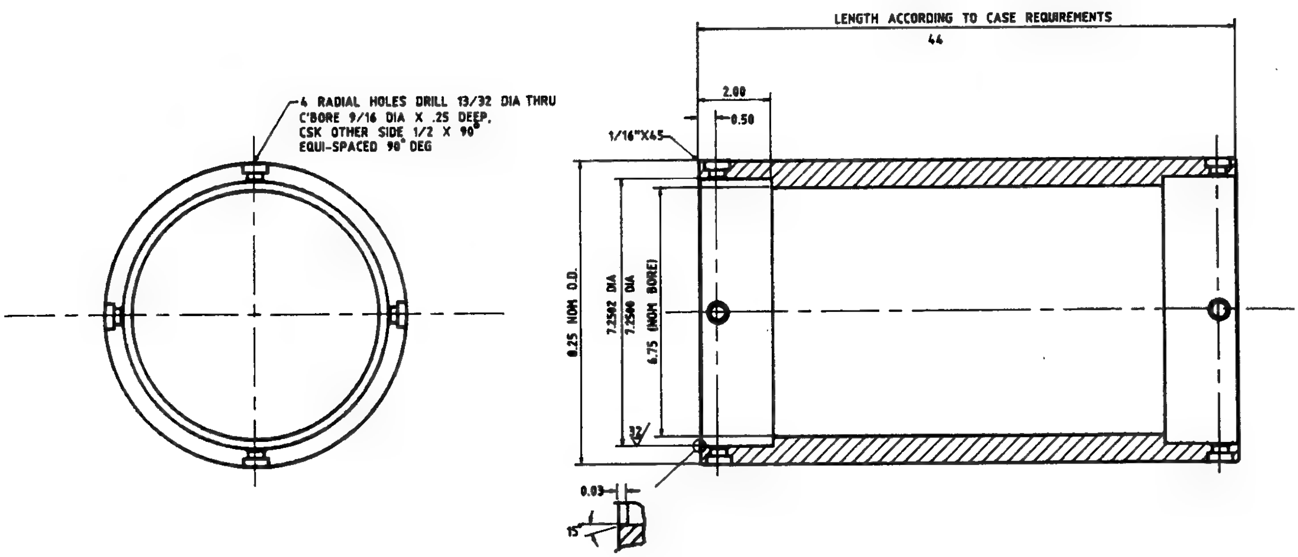
Figure 10: Block diagram of underwater electronics package.



CAP DETAIL — MATERIAL-POLYETHYLENE - 2 REQD



O-RING GROOVE DETAIL-NTS-



CASE DETAIL MATERIAL-POLYETHYLENE

NOTE -SEALING RINGS ARE "PARKER" CAT NO. 2-262

Figure 11: Polyethylene underwater casing for housing the underwater electronics package.

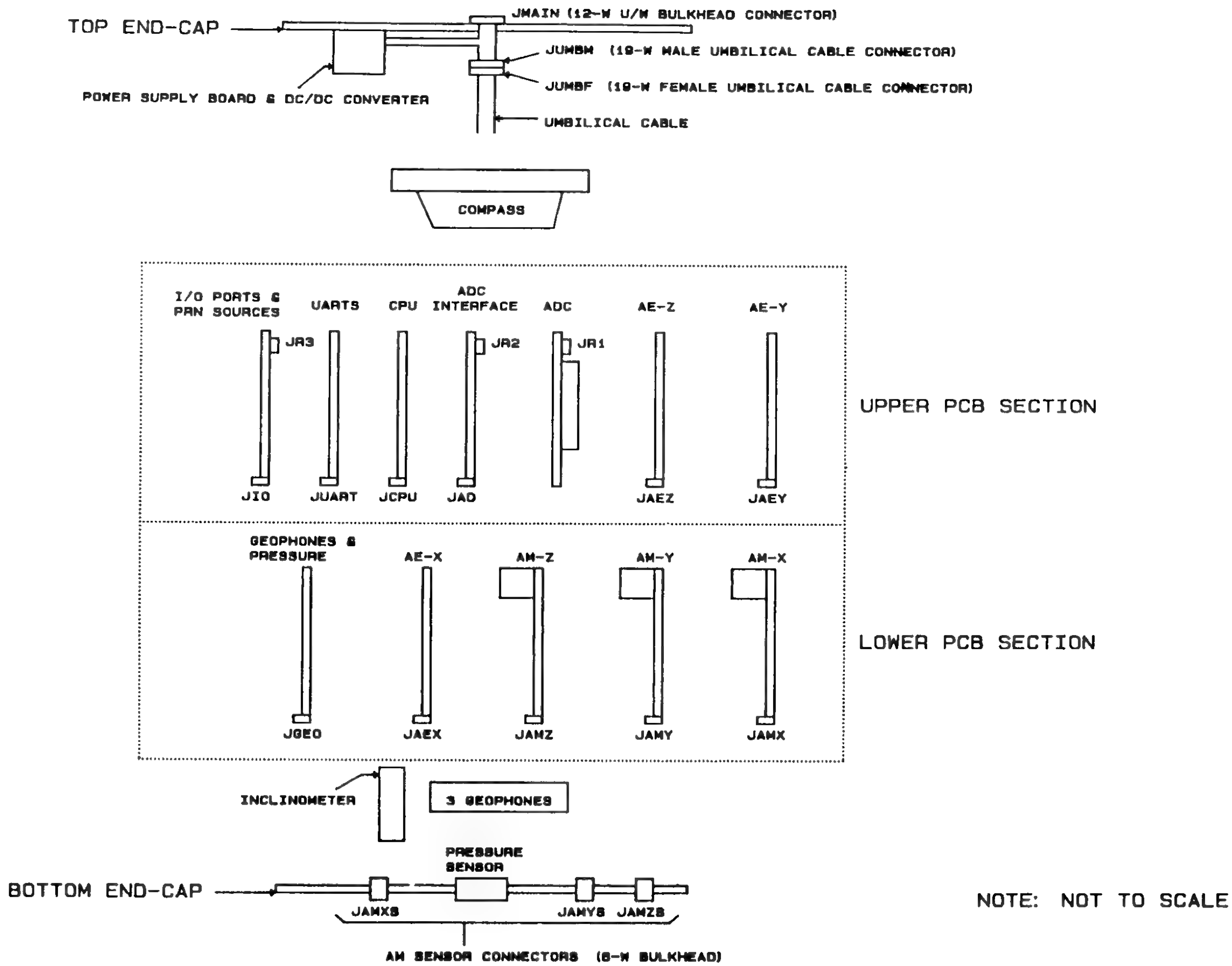


Figure 12: Physical layout of printed circuit boards and sensors contained within the underwater electronics package.

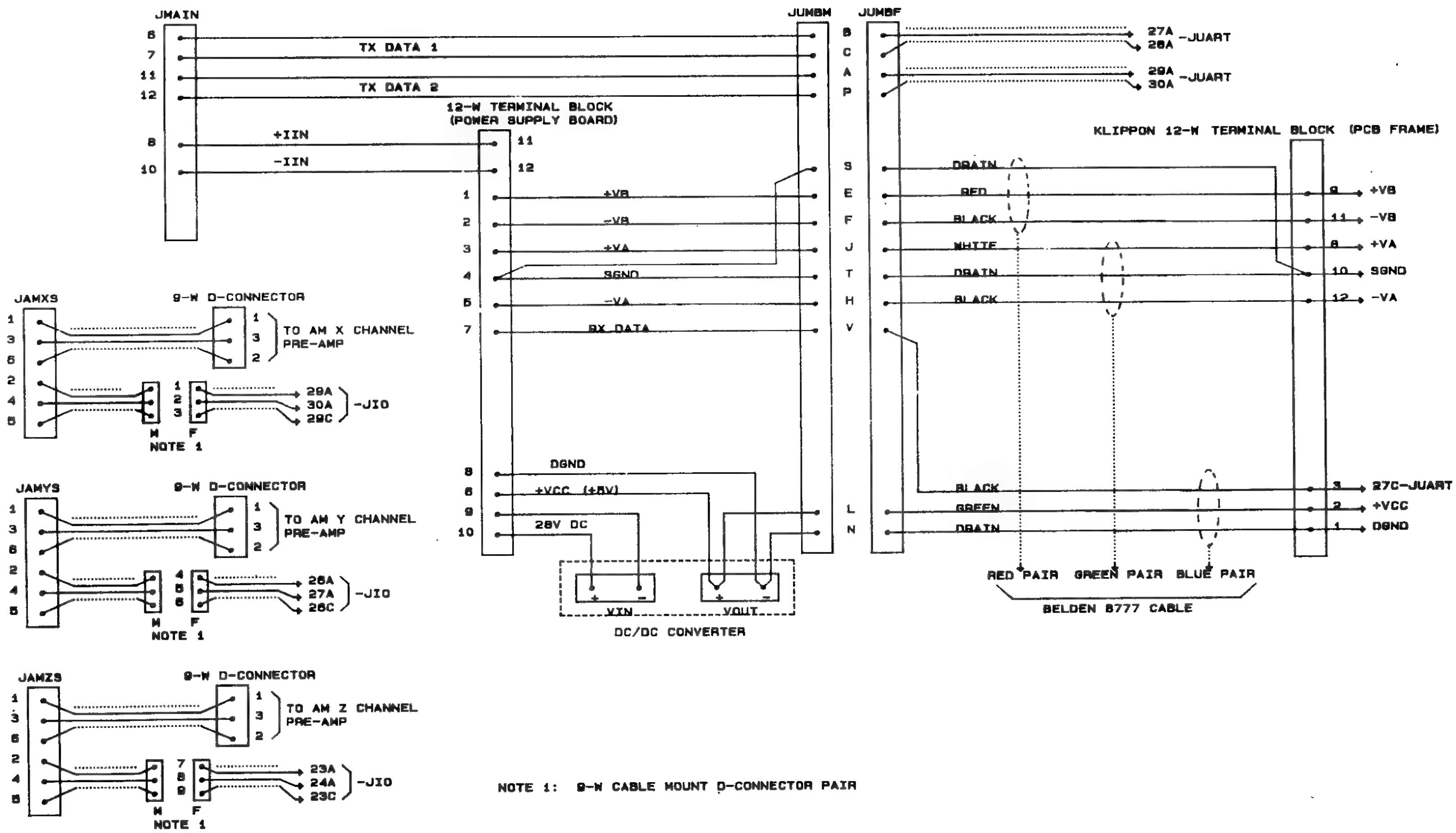


Figure 13: Interconnection diagram for power supply and external sensors.

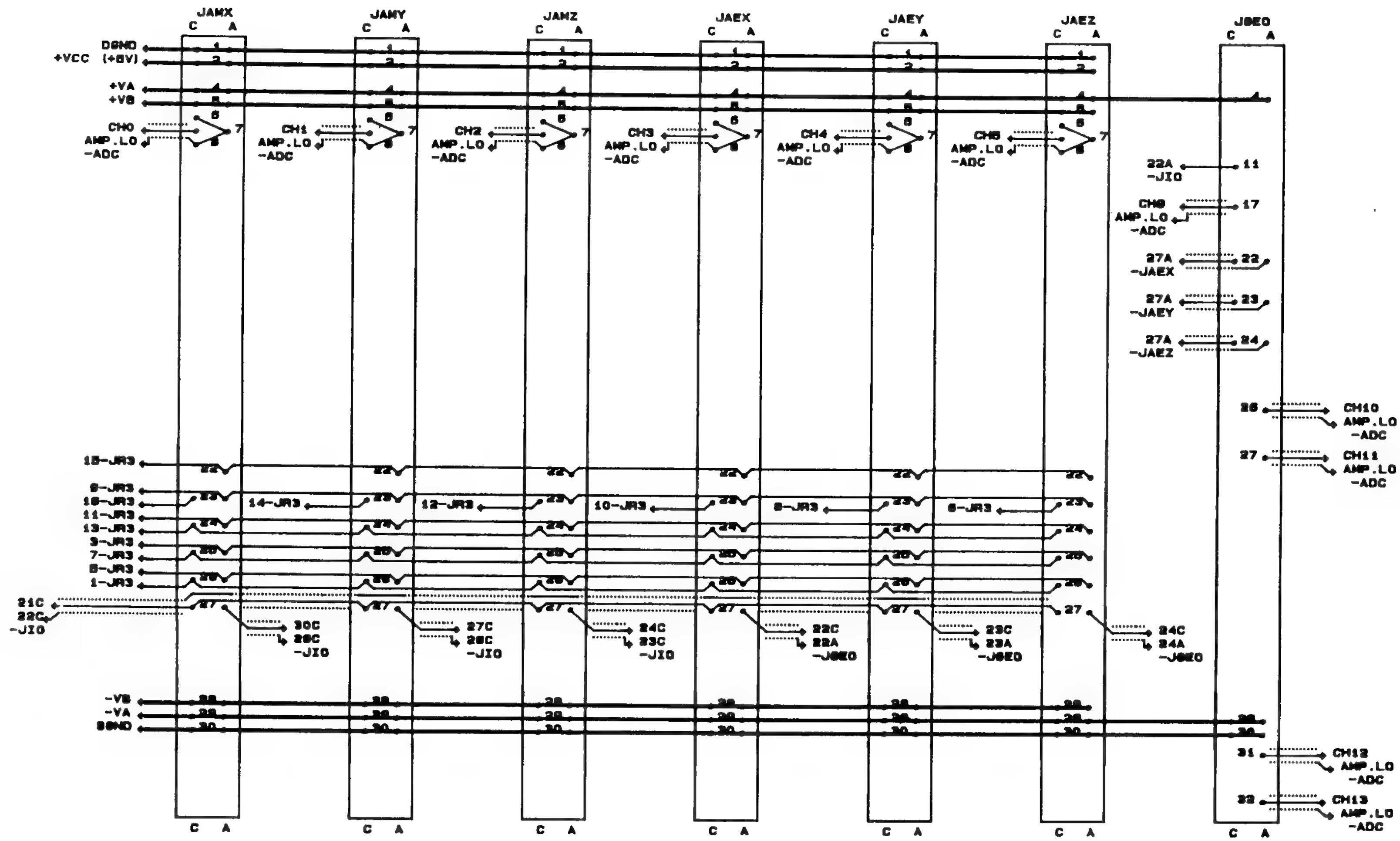


Figure 14: Interconnection layout for alternating magnetic/electric and geophone boards.

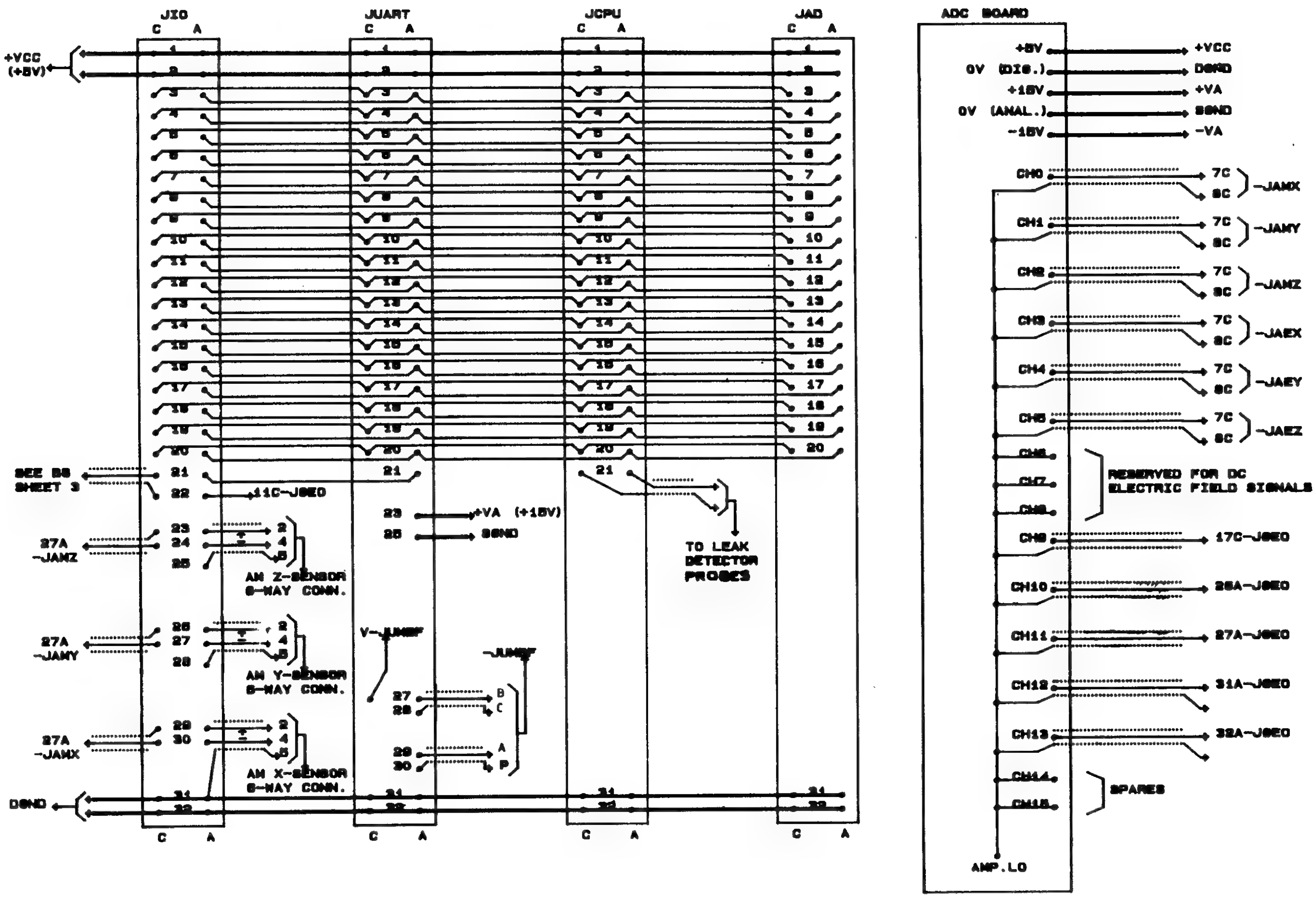


Figure 15: Interconnection layout for I/O ports, UARTs, CPU, AD interface and ADC boards.

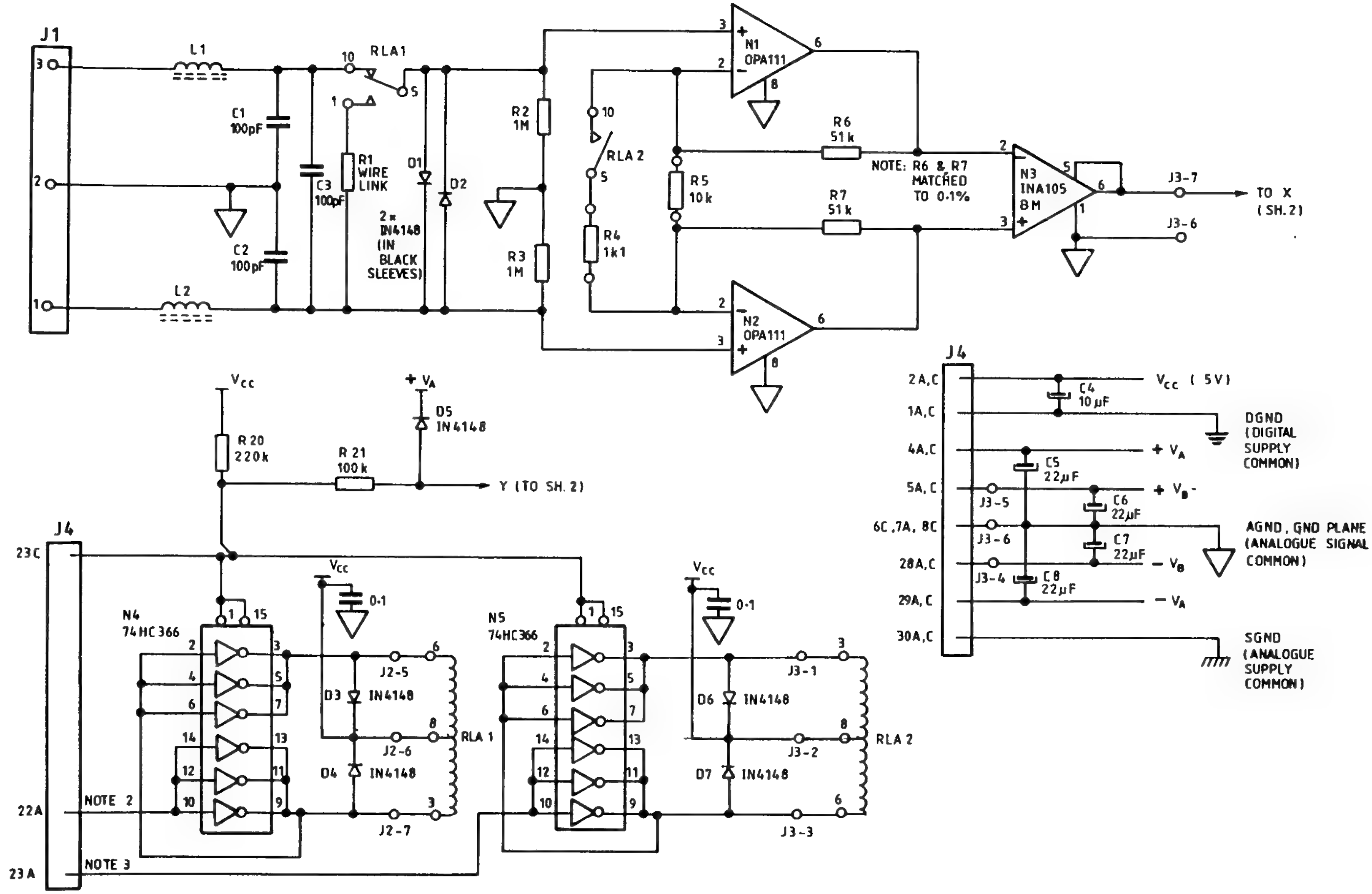
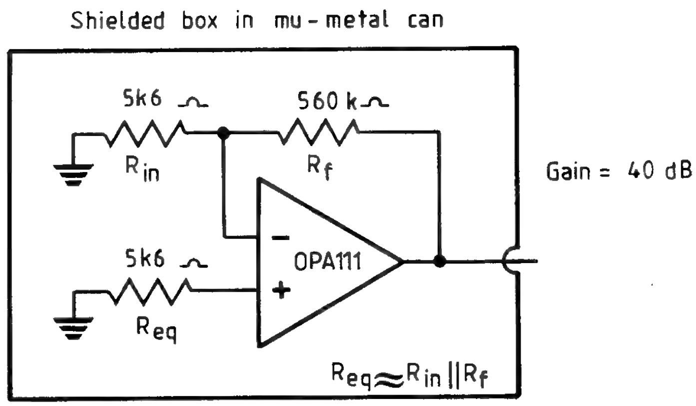


Figure 16: Preamplifier circuitry and supply filter for AM sensor.



$$E_t \approx \{[e_n^2 + (i_n R_{eq})^2 + (i_n R_{in} || R_f)^2 + 4kTR_{eq} + 4kT(R_{in} || R_f)] B_n\}^{1/2}$$

$$i_n \approx 5.10^{-16} \text{ A}/\sqrt{\text{Hz}}$$

$$i_n R_{eq} \approx i_n (R_{in} || R_f) \approx 3.10^{-3} \text{ nV}/\sqrt{\text{Hz}}$$

$$\sqrt{4kTR_{eq}} \approx \sqrt{4kT(R_{in} || R_f)} \approx 10 \text{ nV}\sqrt{\text{Hz}}$$

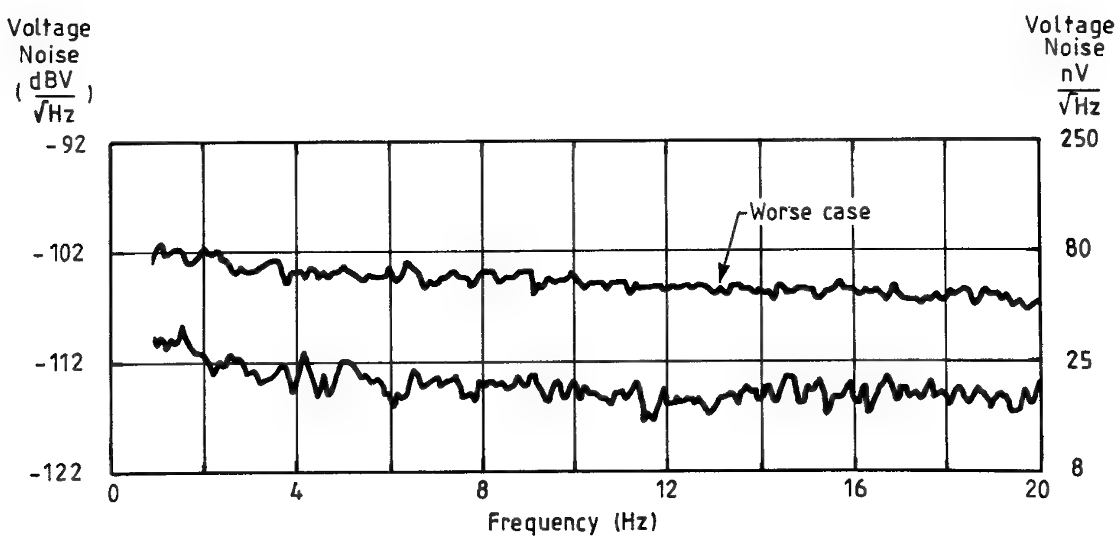
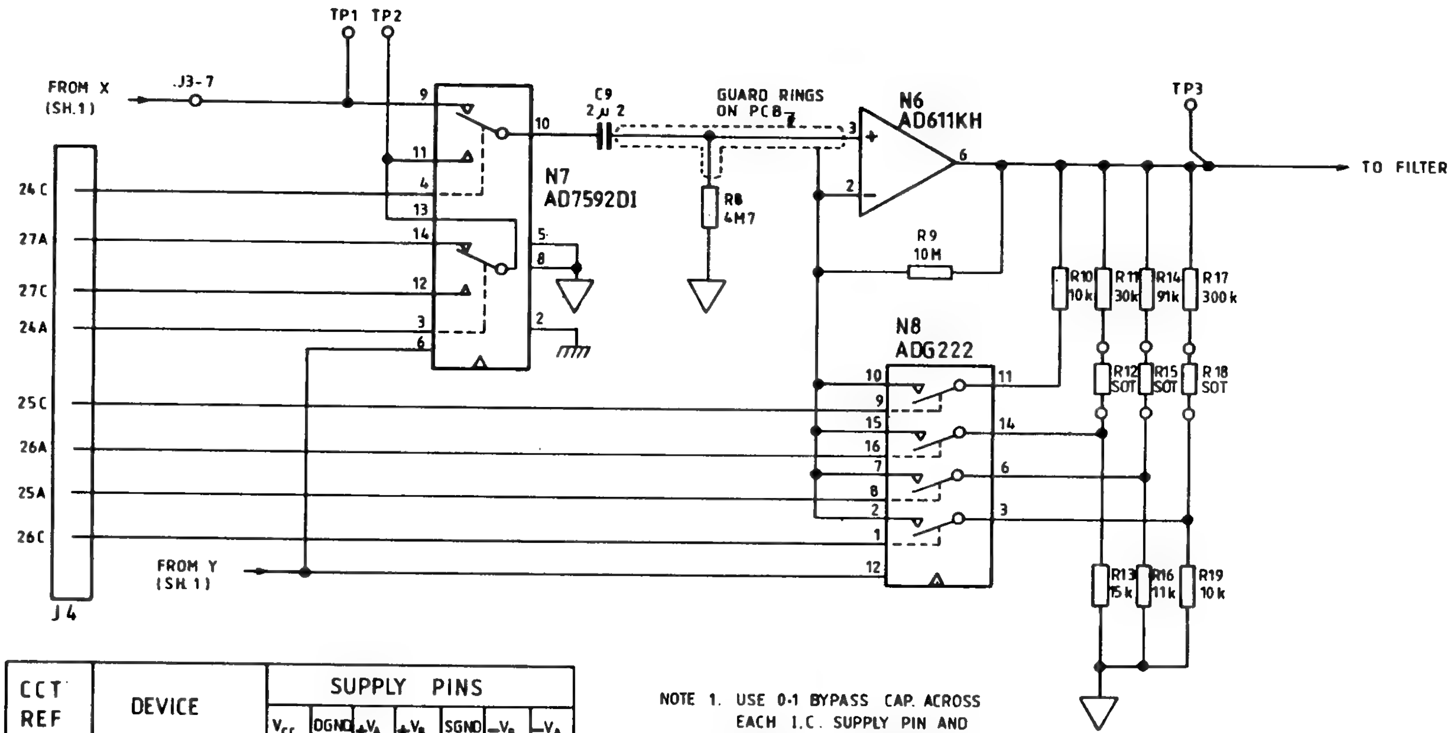


Figure 17: Noise characteristics for operational amplifier OPA-111.



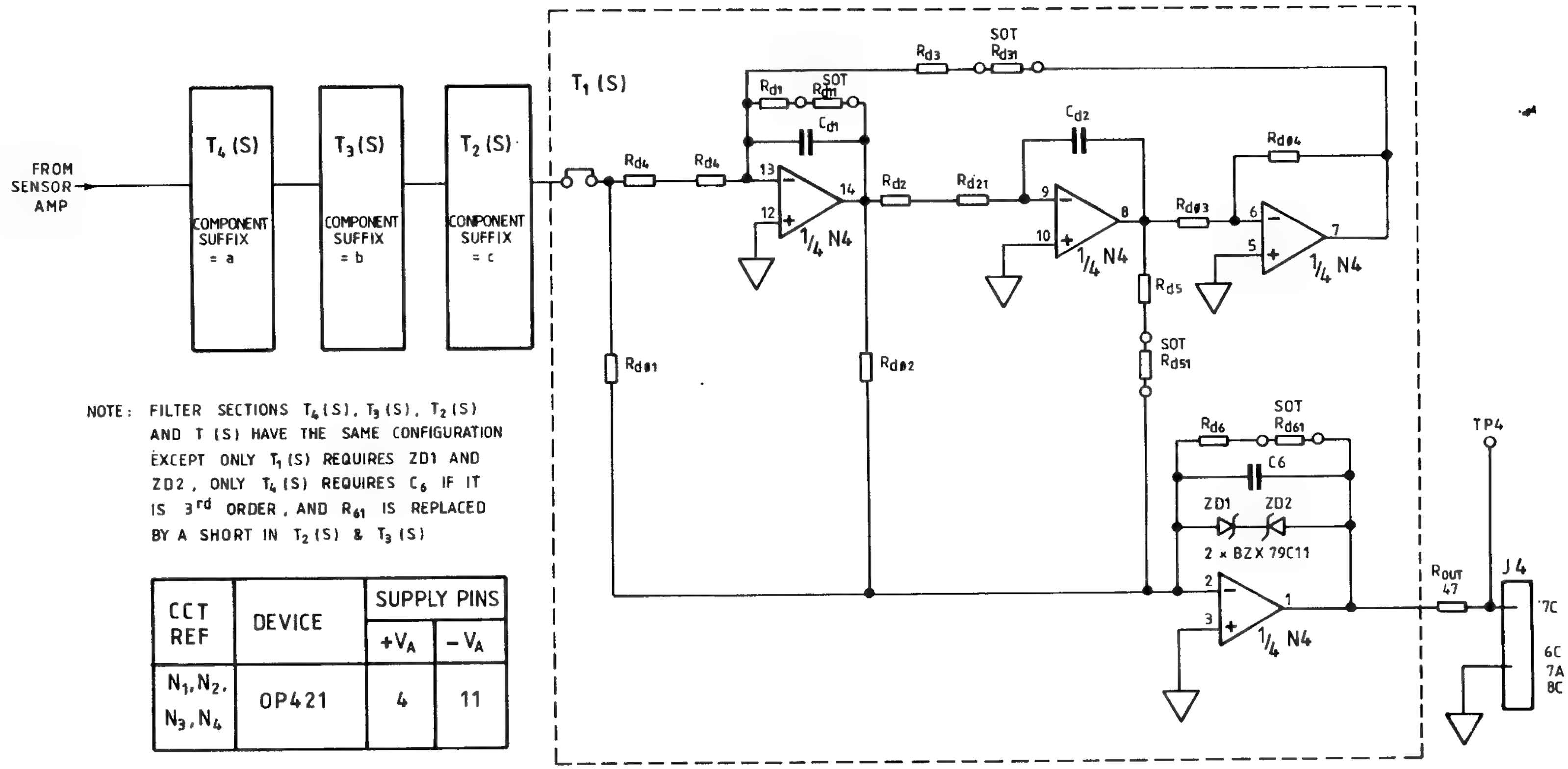
CCT REF	DEVICE	SUPPLY PINS						
		V_{CC}	DGND	$+V_A$	$+V_B$	SGND	$-V_B$	$-V_A$
N1, N2	OPA111				7		4	
N3	INA105 BM				7		4	
N4, N5	74HC366	16	8					
N6	AD611KH			7				4
N7	AD7592DI			7		2		1
N8	ADG 222			13		5		4

NOTE 1. USE 0·1 BYPASS CAP. ACROSS EACH I.C. SUPPLY PIN AND ANALOGUE SIGNAL COMMON EXCEPT N4 & N5

NOTE 2 PIN 22A/J4
LOGIC H SELECTS R1
L SELECTS SENSOR INPUT

NOTE 3. PIN 23A/J4
LOGIC H SELECTS 40 dB GAIN
L SELECTS 20 dB GAIN

Figure 18: Postamplifier circuitry for AM sensor.



NOTE: FILTER SECTIONS T_4 (S), T_3 (S), T_2 (S) AND T (S) HAVE THE SAME CONFIGURATION EXCEPT ONLY T_1 (S) REQUIRES ZD1 AND ZD2, ONLY T_4 (S) REQUIRES C_6 IF IT IS 3[rd] ORDER, AND R_{61} IS REPLACED BY A SHORT IN T_2 (S) & T_3 (S)

CCT REF	DEVICE	SUPPLY PINS	
		$+V_A$	$-V_A$
N_1, N_2, N_3, N_4	OP421	4	11

Figure 19: Eighth-order elliptic low-pass anti-aliasing filter.

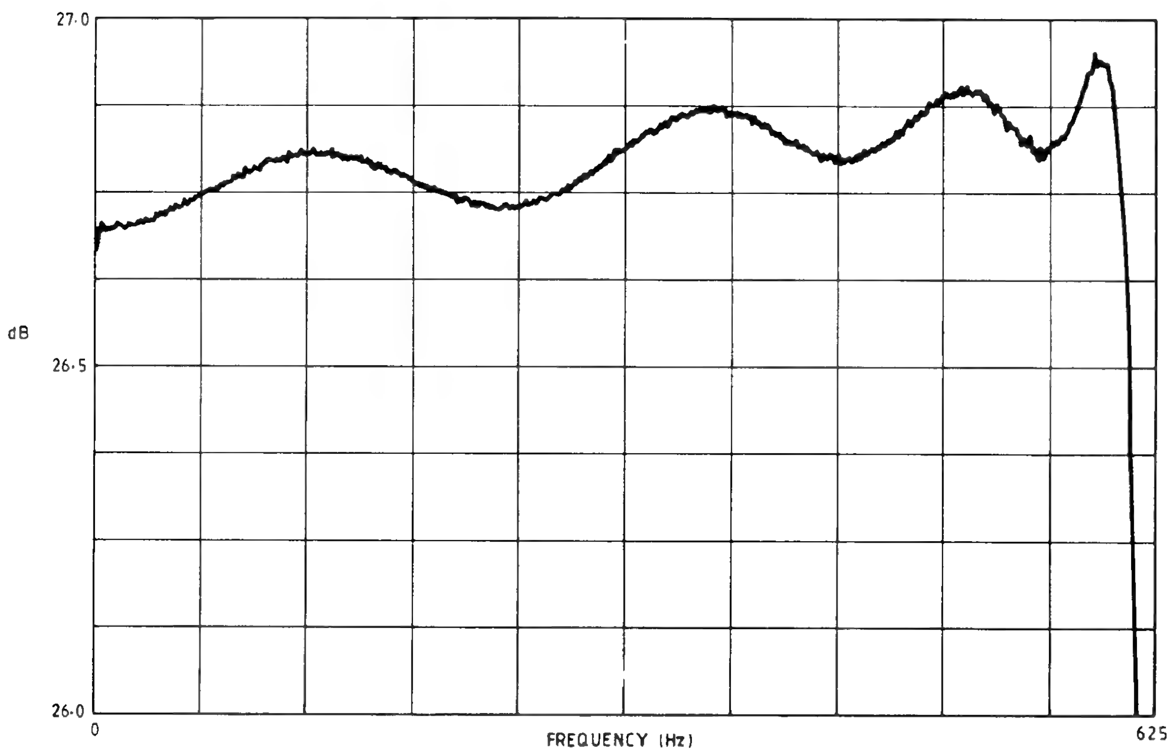


Figure 20: Pass-band response of anti-aliasing filter (preamplifier 20 dB, postamplifier 0 dB, filter 6 dB).

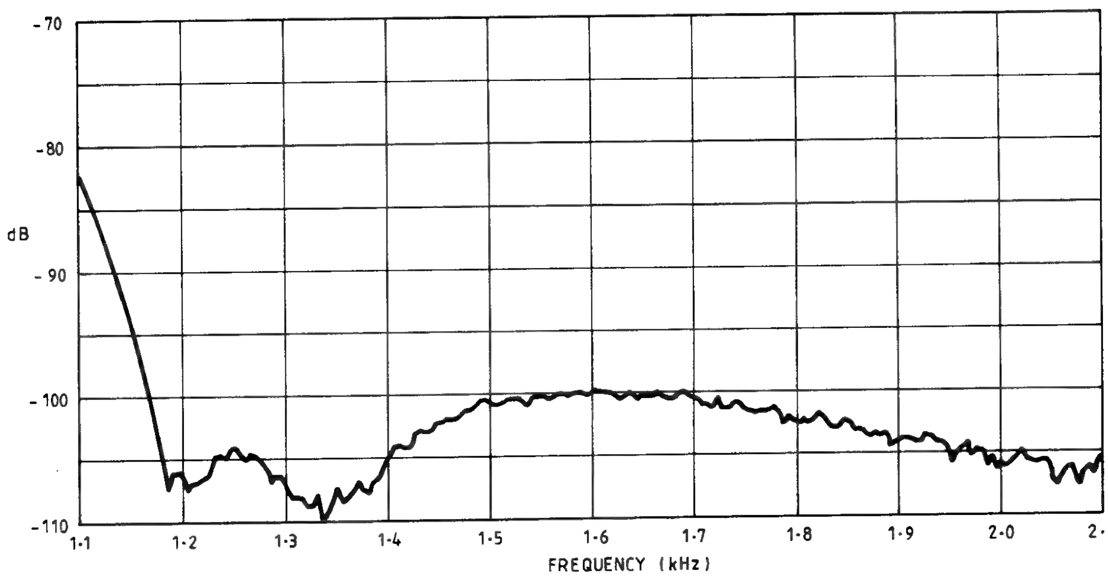


Figure 21: Stop-band response of anti-aliasing filter (filter board only, 6 dB).

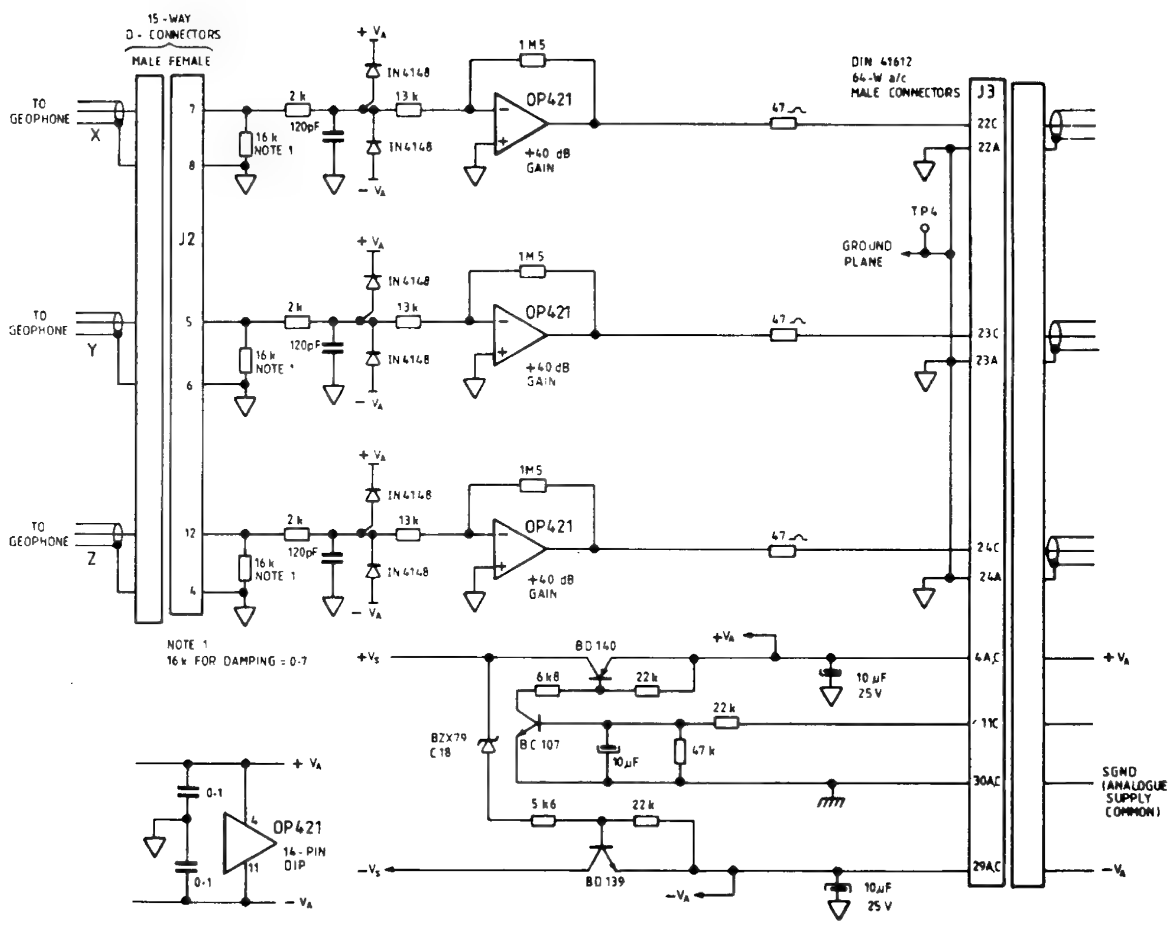


Figure 22: Amplifier board for geophones.

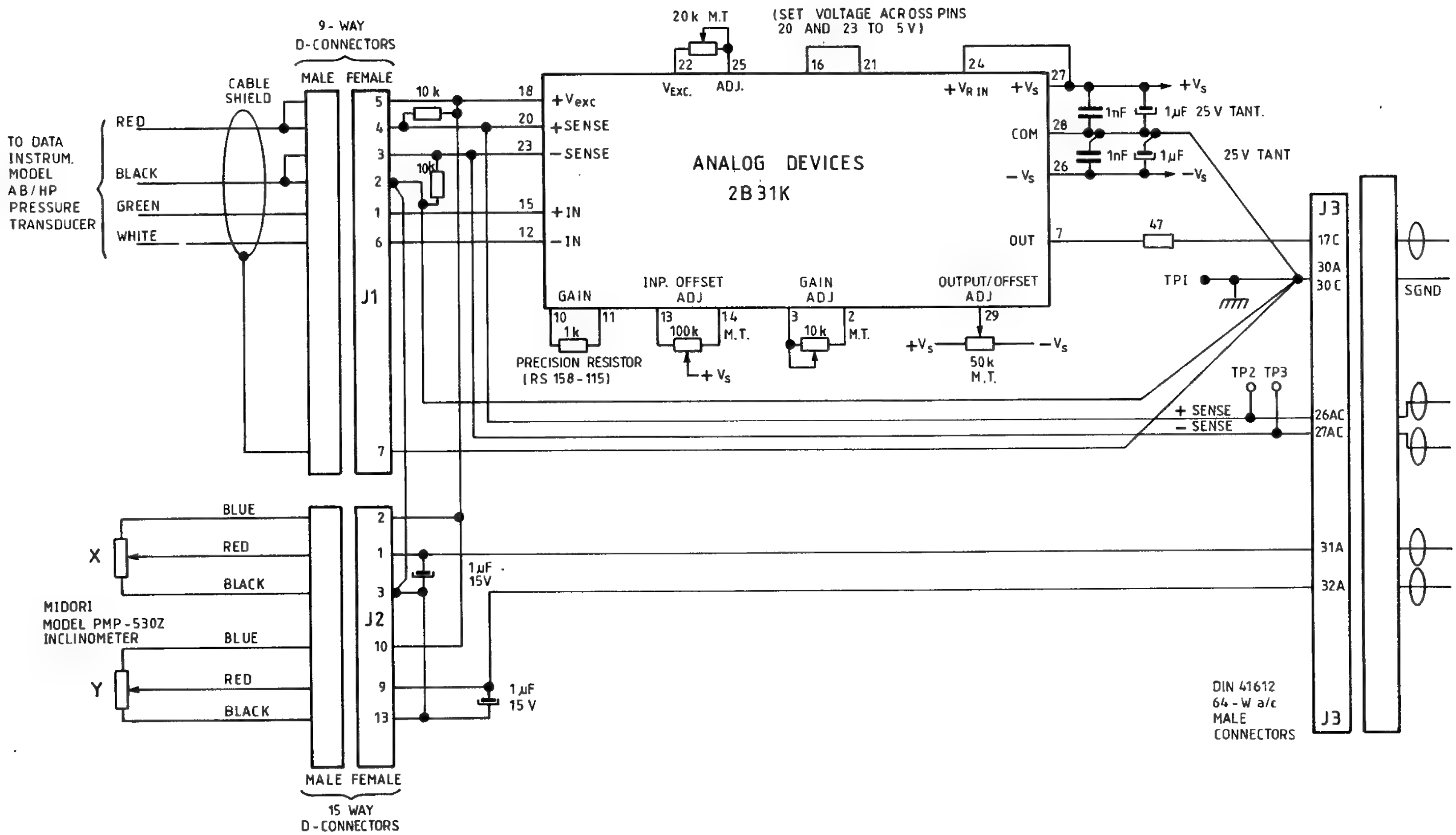


Figure 23: Amplifier board for ancillary sensors: pressure depth and inclinometers.

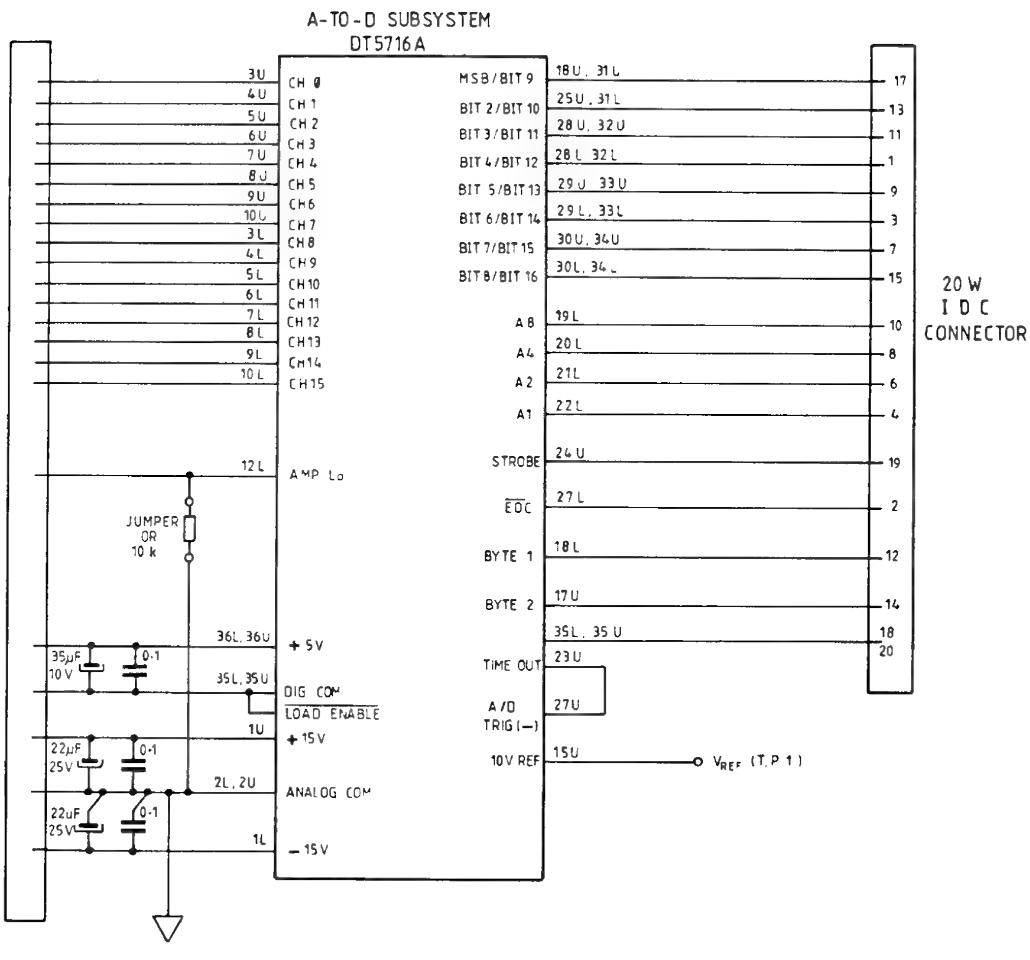


Figure 24: Adapter board for the Analogue to Digital converter.

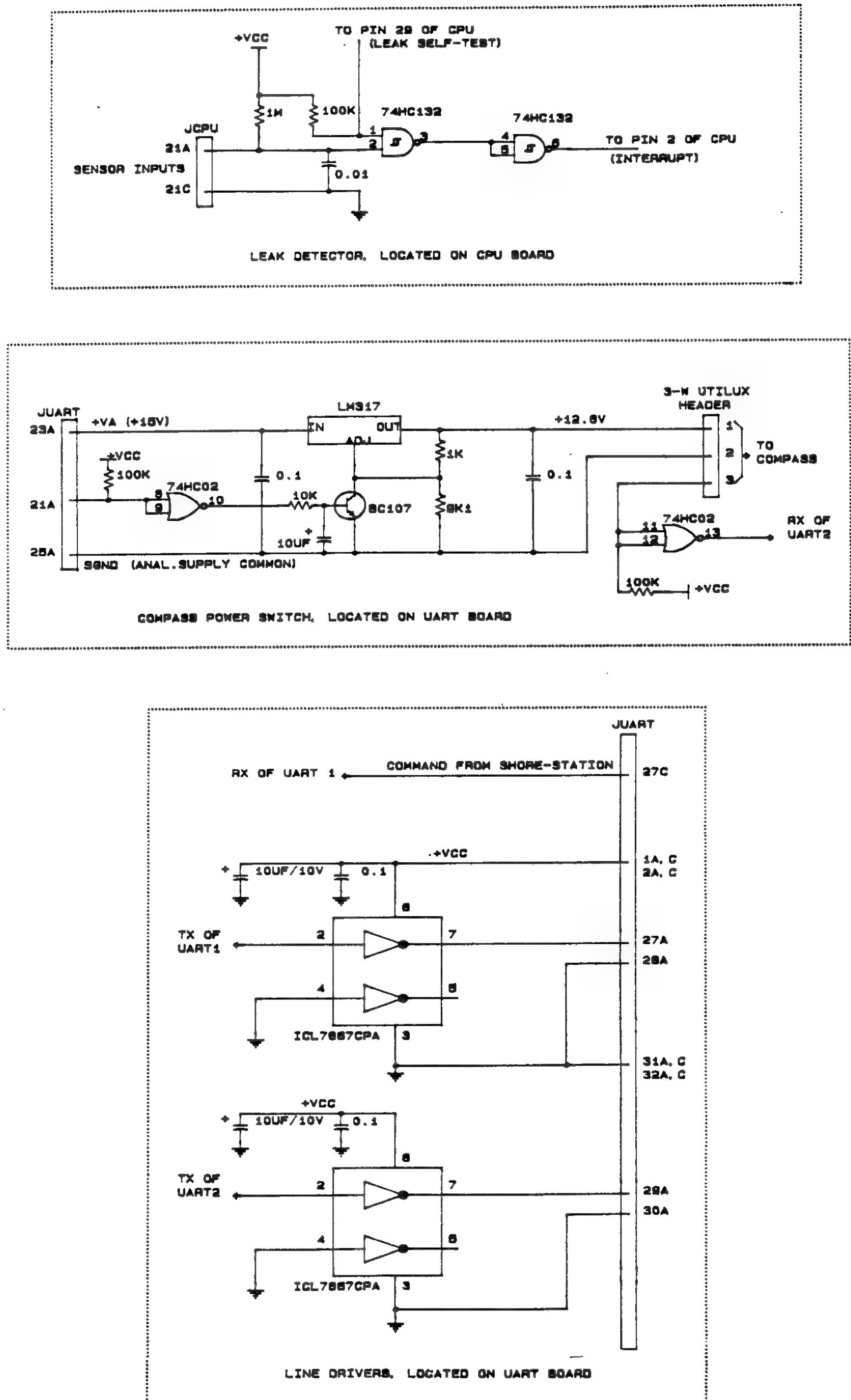


Figure 25: Line drivers, leak detector and compass power switch circuitry.

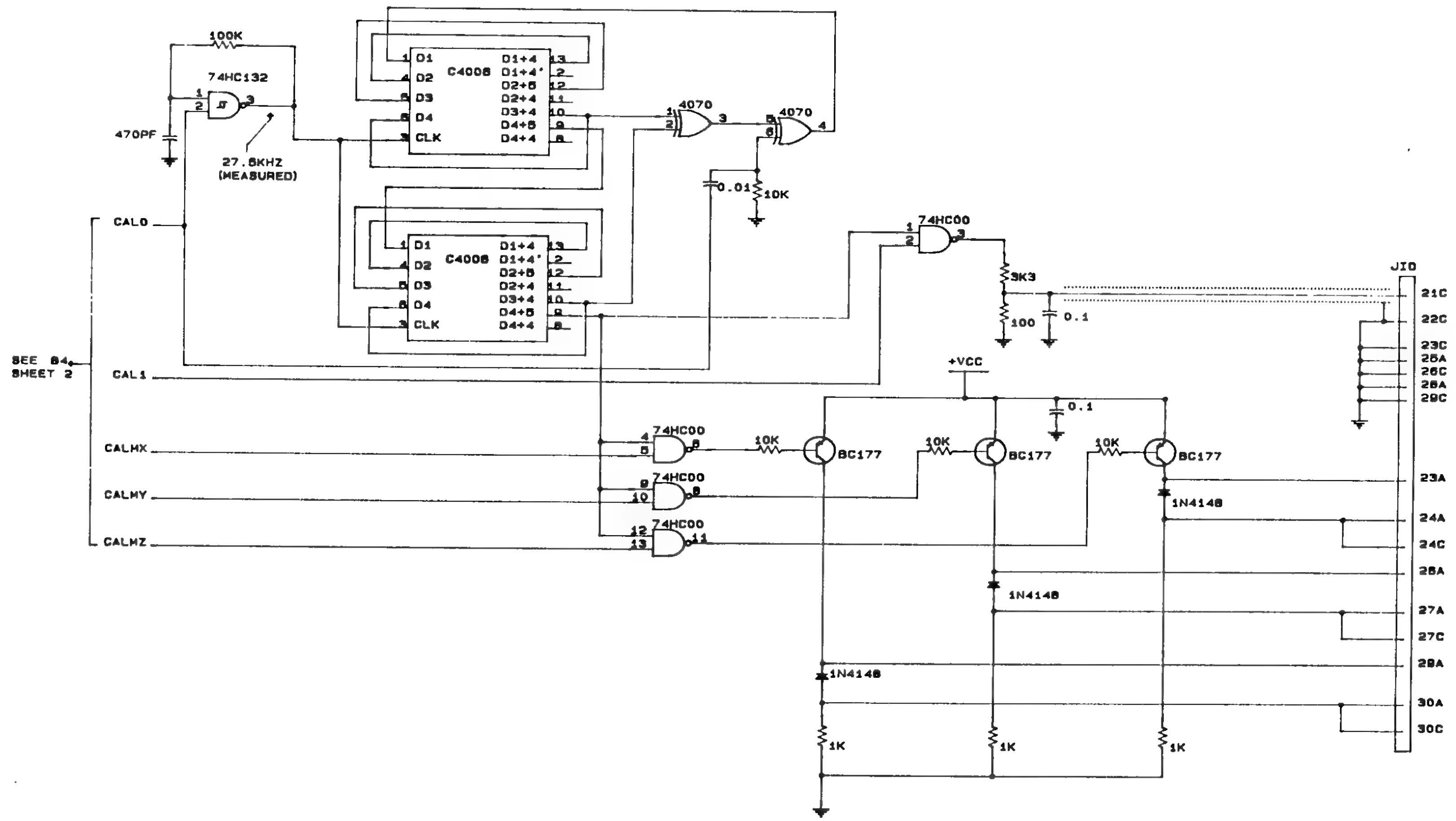


Figure 26: I/O ports and pseudo random noise generator circuitry.

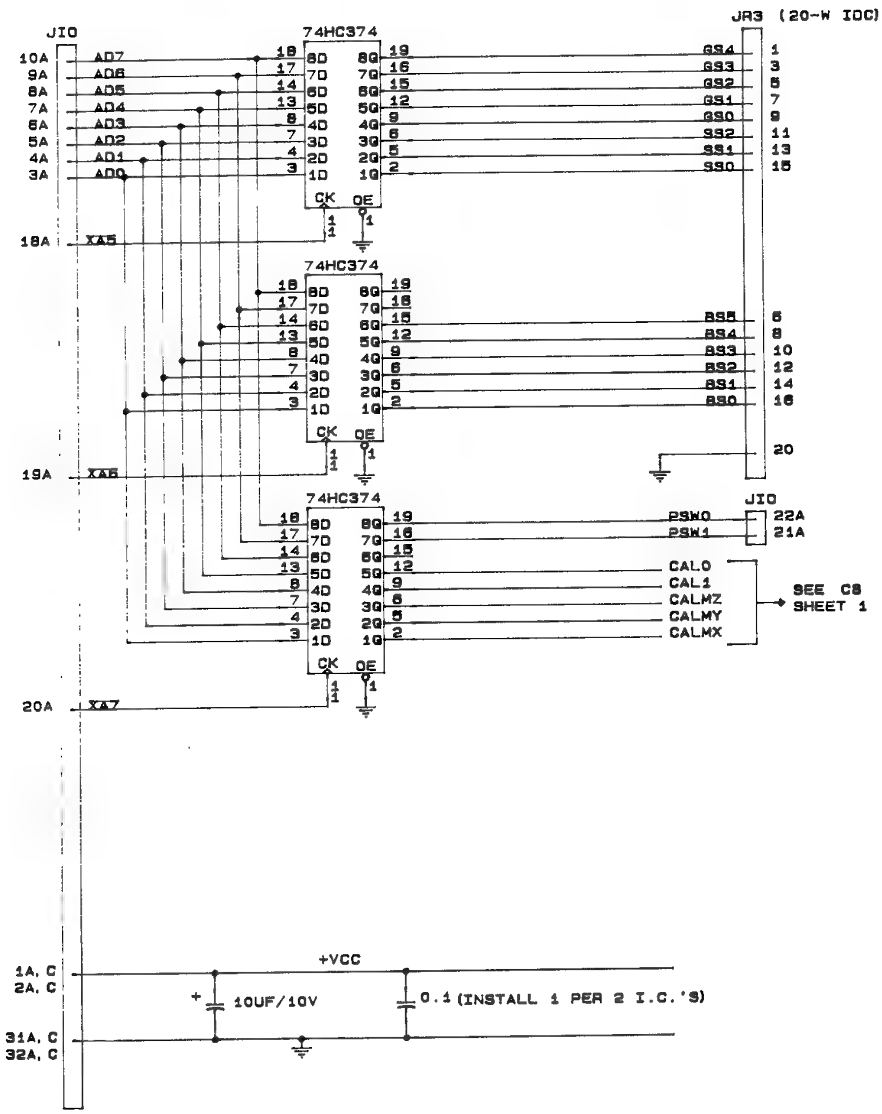


Figure 27: I/O ports and pseudo random noise generator circuitry, continued.

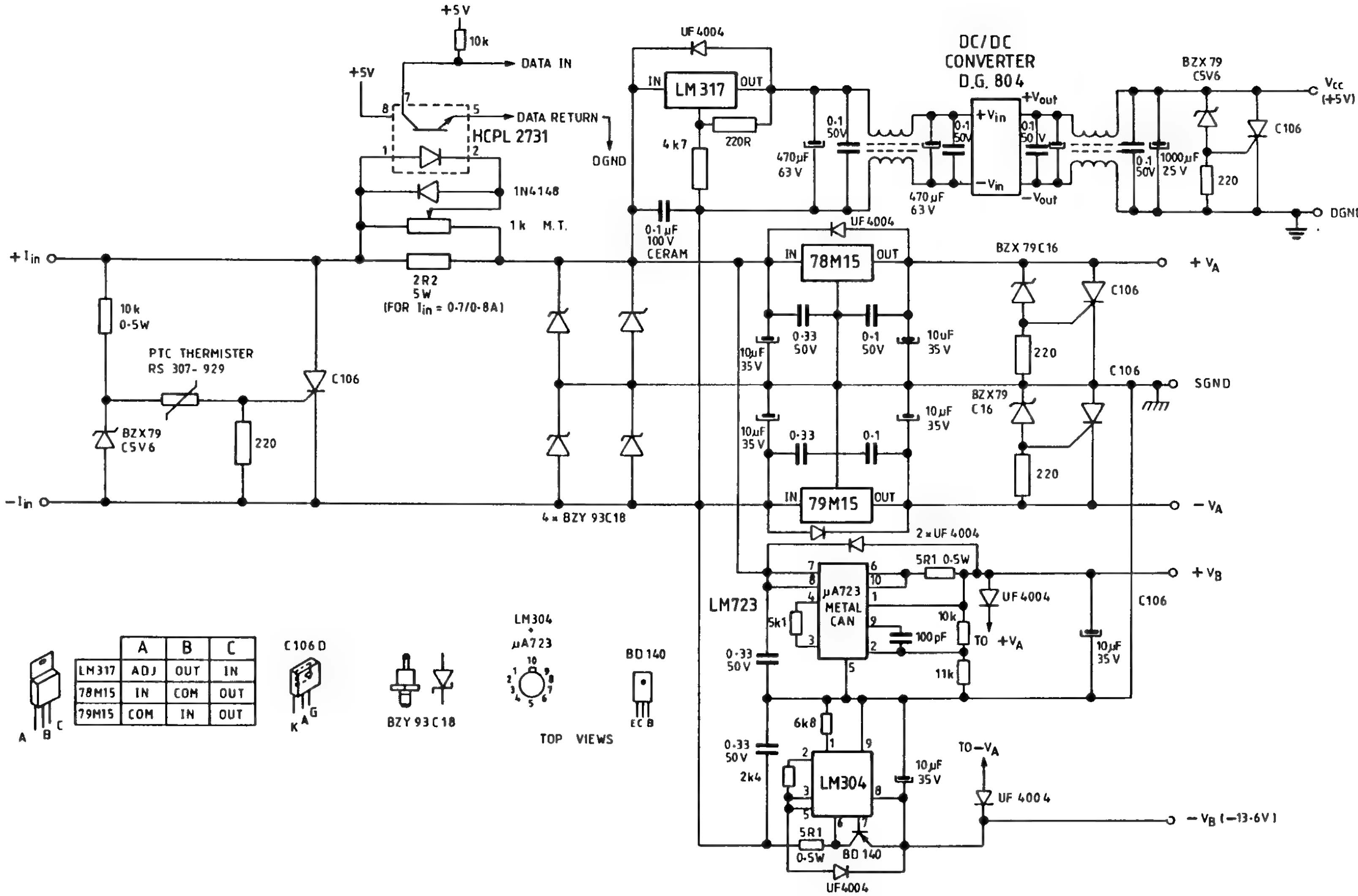


Figure 28: DC power supply for the underwater electronics package.

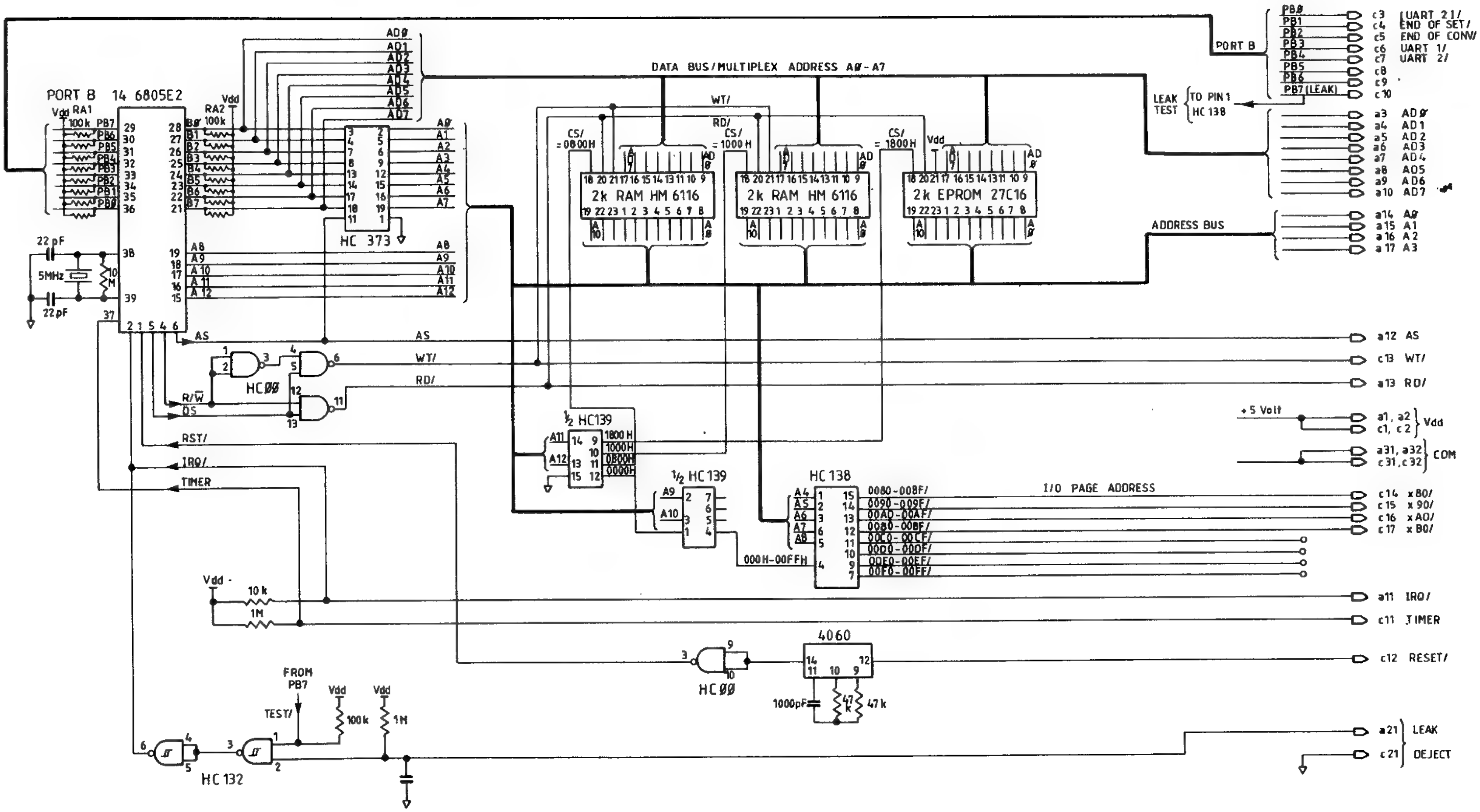


Figure 29: System controller circuit diagram.

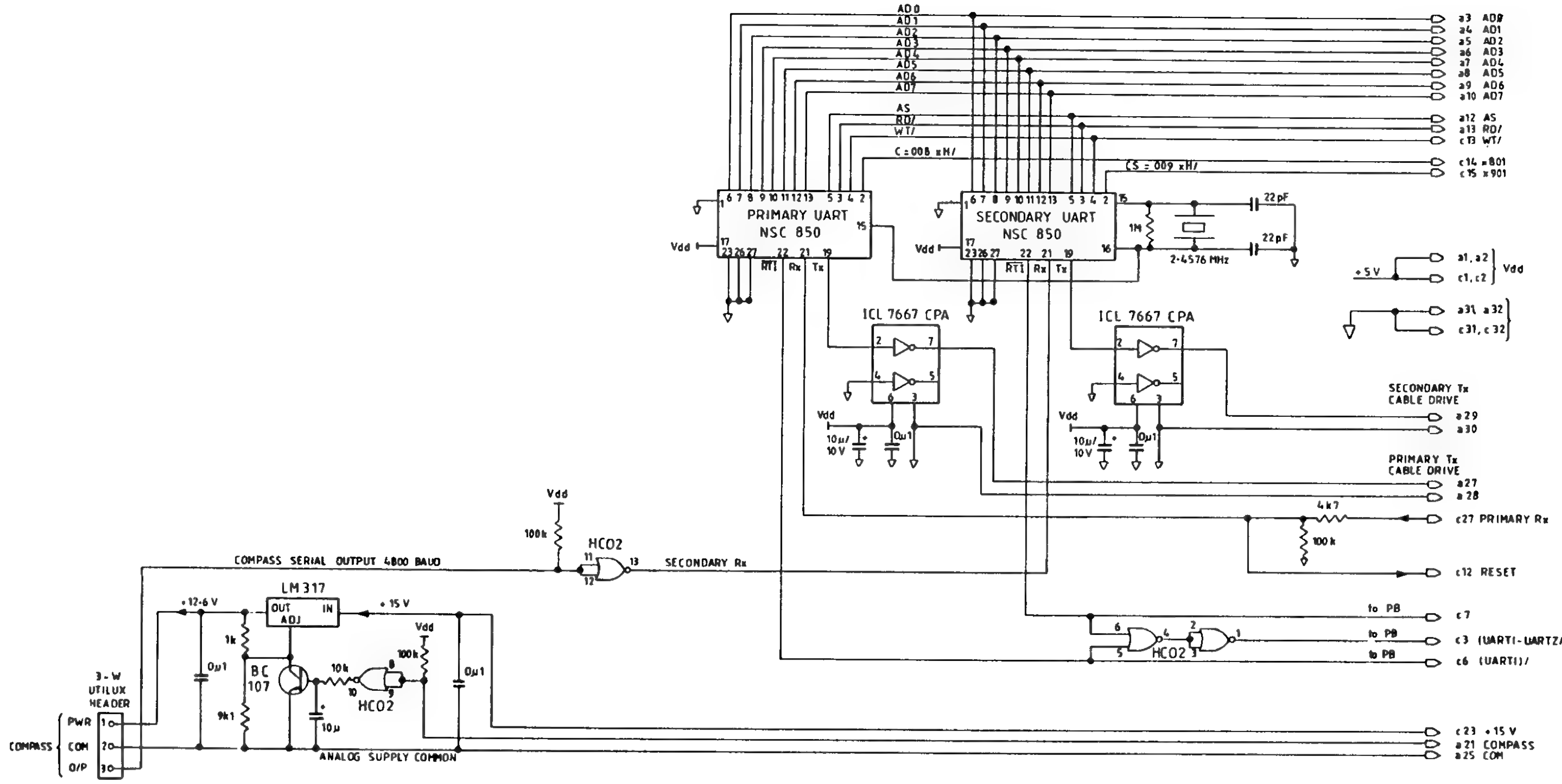


Figure 30: Serial I/O circuit diagram.

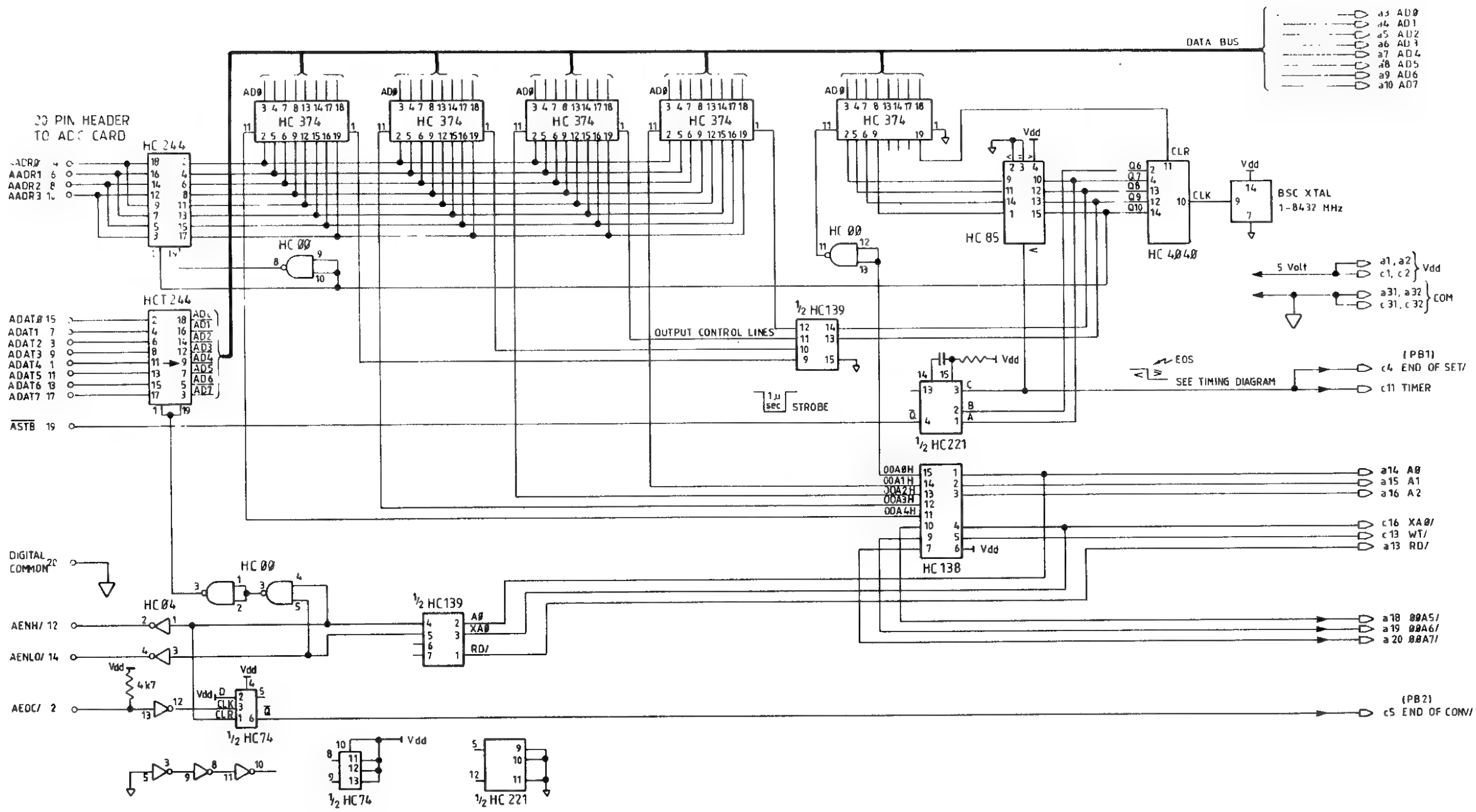


Figure 31: Analogue to Digital converter interface diagram.

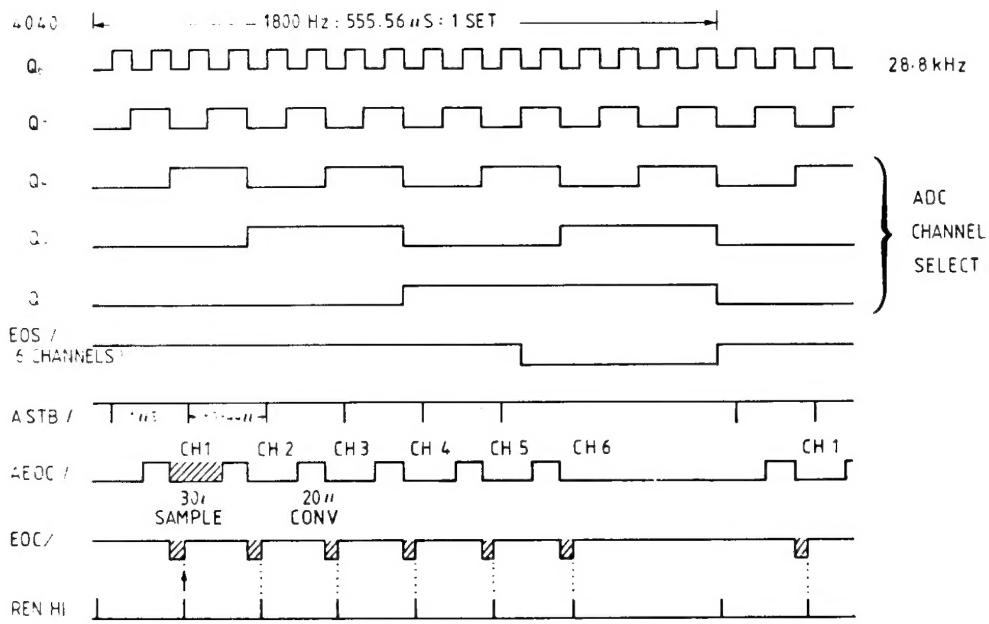


Figure 32: Timing sequences for the Analogue to Digital converter control card.

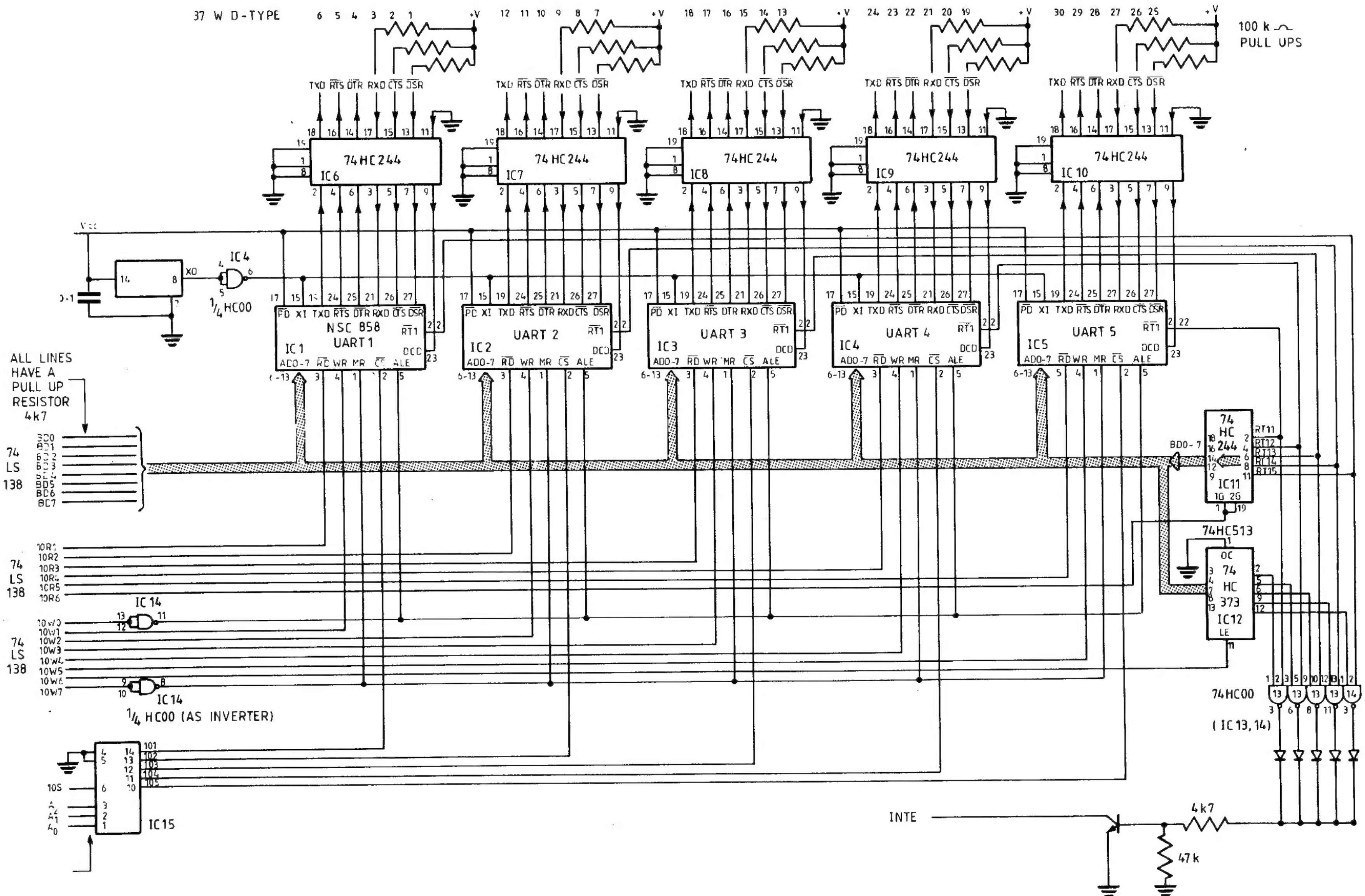


Figure 33: Five UART plug-in for IBM compatible PC.

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TITLE

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Magnetic fields	Data transmission	Electronic test equipment

ABSTRACT

This handbook describes the digital data acquisition system built to record data in the 1 Hz to 600 Hz bandwidth from the portable underwater extremely low frequency (ELF) electromagnetic sensor unit. The sensors supported by the acquisition system are three-axis alternating magnetic field detection coils, three-axis alternating electric field sensors (electrodes) and three-axis seismic sensors; plus ancillary sensors such as pressure-depth, inclination and compass heading. The data acquisition system consists of the wet-end electronics package incorporating the controller board, 16 bit analogue to digital converter, low noise preamplifiers etc. and the dry-end electronics unit incorporating the power supply and computer. The data acquisition software for remote control of the total system and the analysis software which is linked to the data acquisition system is also presented. The analysis software which is purposely designed as an integral part of the acquisition system provides frequency domain spectral information (via the fast Fourier transform (FFT) algorithm) from the raw time series data and may be used both for quick look analysis during the data acquisition phase and for full analysis of data in slow time.

Handbook for the Extremely Low Frequency (ELF) Data Acquisition and Analysis System

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